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Roadway Safety - A Review of the Ontario Experience and Relevant Work Elsewhere

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Abstract:

The report is divided into 4 sections, plus two appendices. Section 1, an introduction, describes the nature, methodology, scope and limitations of the project. Section 2 explores strategic directions for roadway safety research in Ontario. Using the framework described in Section 2, Section 3 identifies and prioritizes specific research programmes. The final section reviews some current road safety research programmes in other jurisdictions, and examines the programme recommended to the Ministry of Transportation of Ontario (MTO) in light of this review.

The research recommendations are based on reviews of literature concerning safety of various roadway elements. These reviews are summarized in Appendix A. Each review begins with a statement of the issues, descriptions of MTO policy, and an Ontario accident experience, and ends with a qualified appraisal of the state of knowledge, an assessment of MTO policy, and a statement of research needs.

Appendix B provides detailed summaries of data on which some of the accident profiles are based. These summaries developed from analysis of traffic, inventory information, and accident data for Ontario roads under MTO's jurisdiction.

Comments: This report is a part of Research and Development Project 21217.

Key Words: roadway safety, roadside safety, roadway elements, accidents, road safety management, roadway safety research, road safety, R&D priority ranking

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PREFACE

This report has undergone several revisions since the original draft in November 1990. As revisions were in progress, new information became available. Thus, although the project officially ended with the submission of a revised draft final report in March 1991, an attempt has been made to update the current version (December 1991) to incorporate new information that has become available since March 1991.

The report is structured into 4 sections plus two appendices. Section 1 is an introduction that describes the nature, methodology, scope and limitations of the project. This is followed by what can be seen as the substance of the report -- the development of a set of recommendations for roadway safety research to be initiated by MTO (Ministry of Transportation, Ontario) -- which is described in two sections. The first of these, Section 2, explores strategic directions for roadway safety research and is contributed by Dr Ezra Hauer, a sub-consultant on the project; the second, Section 3, uses the framework described in the Section 2 to identify and prioritize specific research programmes. The final section (4) reviews some current road safety research programmes in other jurisdictions and examines the programme recommended to MTO in the light of this review.

The research recommendations are based on a review of samples of literature on safety of various roadway elements. These reviews are summarized in Appendix A. Each review begins with a statement of the issues and descriptions of MTO policy and Ontario accident experience, and ends with a qualified appraisal of the state of knowledge, an assessment of MTO policy, and a statement of research needs.

Appendix B provides detailed summaries of data on which some of the accident profiles are based. These summaries are based on analysis of traffic and inventory information and accident data for Ontario roads under MTO's jurisdiction.

In addition to Dr Hauer, there were several important contributors to the research whose efforts need to be acknowledged. The guidance and assistance of Alex Ugge, the project monitor, was vital, as were the comments of the MTO Roadway Safety Committee on earlier drafts. Alex Kazakov and his staff were instrumental in providing accident data for the analysis that forms a key aspect of this report. Several highway agencies across North America provided research reports that are not available through normal channels. Finally, special thanks go out to three Ryerson students, Troy Austrins, Les Dzbik and Festus Idahaso who worked diligently on many aspects of the project. That the latter two have since gone on to higher endeavours in Transportation research is evidence that the student training objective of OJTRP research is a worthwhile one.

1. INTRODUCTION

1.1 **Background**

Sound traffic safety management requires a knowledge of where safety problems exist, along with an understanding of how the various elements of the physical roadway system affect safety. The depth and consistency of this understanding varies from element to element. Thus to focus and prioritize roadway related research and development, it is necessary not only to explore where the efforts should be concentrated but also to assimilate what has been learnt within and outside MTO from experiences with specific roadway elements of interest. Such knowledge could then serve as a base for assessing how much (if any) safety research needs to be done on specific roadway safety issues and for identifying which elements are likely to yield the best safety benefits if subjected to an appropriate level of research.

1.2 **Objectives/Scope**

The objectives of the project are derived from the "Request for Proposal" (RFP) which called for "a review of Ontario experience and relevant work elsewhere to identify roadway elements that may contribute to safety problems in Ontario" and to provide:

1. - "A priority ranking of identified elements in order of the potential for highest safety benefits which may result from an in-depth study of the element".

2. - "Need definitions for research and development work to resolve safety problems on the priority list that are unique to Ontario, or that are relevant, but about which there is no current body of knowledge that can be adapted to MTO's needs".

3. - "A strategic direction for roadway safety related research and development to establish a long range, needs driven focus for roadway safety research in the Ministry."

The scope of the research was necessarily limited in a number of aspects. First, after discussion with MTO staff it was decided to confine the project to elements relevant to <u>roads under MTO jurisdiction</u>. Second, the project was confined to research on the physical aspects of the roadway and roadside only and then only to the safety aspects. This limitation excluded, for example, issues such as safety of elderly

drivers, truck safety, and driver behaviour, along with several aspects of safety legislation. Third, the limited accident data available when the research was done places some limitations on the strength of conclusions based on MTO data.

1.3 Research Procedure

The last objective identified above and aspects of the second are addressed first in this report since this sets the framework for our research recommendations. The resulting section on strategic directions was prepared on the basis of the substantial experience we have gained in road safety research, our familiarity with research programmes in other jurisdictions, our experience with using Ontario accident data, and information gleaned from documents provided by MTO and conversations with MTO staff. These proposals for basic research needs and strategic directions conclude with speculation on how a road safety management system might function in Ontario. Further examination of such a system was beyond the scope of the project.

Against the background of how road safety research programmes ought to be carried out, a programme of specific research projects is proposed and prioritized in Section 3 in response to the first objective identified above. The work of providing this programme, focussed on nine tasks:

Task 1: After communications with MTO staff, a number of candidate roadway elements were selected for investigation of research needs. These are listed in Table 1. In view of the time limitations placed on this project, the process for selecting elements was somewhat subjective. Selection criteria included:

- A judgement on whether the element is of interest when considering roads under MTO jurisdiction,

- A judgement on the likelihood of reaching a sensible conclusion on research need,

- A judgement on the likelihood of research altering decisions that are already made on some basis,

- The difficulty of finding relevant research,

- Perceptions of the importance of the element from a safety point of view. These perceptions are based on a combination of an examination of, or an intelligent guess at, the number of target accidents, and an initial judgement on whether target accidents are likely to be substantially reduced by research.

TABLE 1: ORIGINAL LIST OF ISSUES/ELEMENTS FOR EXAMINATION OF SAFETY EXPERIENCE

1. **Cross-section elements**
   - 1.1 Lane width, number of lanes
   - 1.2 Shoulder width
   - 1.3 Shoulder type & condition
   - 1.4 Pavement type & condition
   - 1.5 Median design
   - 1.6 Sideslopes and ditches
   - 1.7 Bridge width and approach
   - 1.8 Rock cuts
   - 1.9 Gore areas

2. **Alignment Elements**
   - 2.1 Vertical curves and gradient
   - 2.2 Horizontal curvature
   - 2.3 (No)passing zones and sight distance
   - 2.4 Climbing lanes
   - 2.5 Passing lanes

3. **Obstacles**
   - 3.1 Barriers and Guardrail
   - 3.2 Drainage structures
   - 3.3 Utility poles, signs, trees
   - 3.4 Abandoned vehicles and trash
   - 3.5 Mail boxes
   - 3.6 Curbs

4. **Traffic control elements**
   - 4.1 Intersection control (signals and stops)
   - 4.2 Prohibitions -- trucks, turns, one-way, parking
   - 4.3 Speed control
   - 4.4 Signing and marking
   - 4.5 Access control, including private driveways

5. **Intersections - General**
   - 5.1 Turn lanes
   - 5.2 Lighting
   - 5.3 Sight distance
   - 5.4 Pedestrian accommodation
   - 5.5 Channelization
   - 5.6 Tapers
   - 5.7 Turning radii

6. **Miscellaneous**
   - 6.1 Railroad crossings
   - 6.2 Roadway lighting
   - 6.3 Bicycle paths
   - 6.4 Billboards
   - 6.5 Wildlife

Task 2: An extensive literature search and communication with major North American highway agencies produced several hundred papers and reports which were critically reviewed. Since the intent was to get a flavour for the knowledge, and because of time and money constraints, the reviews should in no way be construed as comprehensive.

Task 3: Relevant knowledge on each selected element was extracted. The knowledge extracted was in turn sampled and further summarized to provide short summaries that form part of the safety assessments of each roadway element provided as an Appendix to this report. A separate Appendix report contains the detailed extracts.

Task 4: Information on Ontario policy in the form of standards, warrants or guidelines for each selected roadway element was assembled and summarized in one of the opening sections of the safety assessments provided in the Appendix. In some cases it was also of interest to report on other North American policies, particularly when these appeared to differ significantly from Ontario policy.

Task 5: Ontario safety experience was gathered partly from Ontario Road Safety Annual Reports and partly from data supplied by MTO. The reports provide a limited number of tabulations for accidents in the entire province, so one can only speculate on the experience for Ontario roads which account for only about 20% of the accidents covered in the tabulations. By the end of the project, however, it was possible to supplement this information with accident experience extracted from traffic, inventory and accident data provided by the MTO for Ontario road sections. This process involved writing computer programmes to link the 3 sources of data and using SPSS software to extract profiles of accidents related to the element. The Ontario safety experience is summarized in the opening sections of the safety assessments in Appendix A. These brief accident profiles were extracted from the annual reports and from tabulations based on the data analysis. The more detailed tabulations, along with appropriate explanations, are shown in Appendix B. *Although detailed accident became available near the end of the project, it should be stressed that the bulk of the analysis was based on the limited datasets available earlier. This difficulty, as indicated earlier, places some limitation on the strength of our findings.*

Task 6: The knowledge reviewed was evaluated for soundness and applicability to Ontario in the 1990's. Ontario policy and accident experience were examined in the light of any knowledge thought relevant and useful, and vice versa, and a preliminary, cautious assessment was made of the Ontario experience. The words "preliminary" and "cautious" are used because, while an assessment is needed to make research recommendations, it is the same research that is needed to provide a firm assessment in many cases.

Task 7: On this basis of the evaluation of knowledge and of the Ontario experience, short statements of research need were prepared. These statements, which form the final sections of the safety assessments provided in the Appendix, are not intended to address cost-effectiveness of the research or how the research should be prioritized.

Task 8: Research needs identified in the assessments were assembled and prioritized using a procedure described in Section 3. It is at this stage that the value of research was considered.

Task 9: Safety research programmes for other jurisdictions were reviewed in the light of the findings of this research project. This review is presented in Section 4.

2. STRATEGIC DIRECTIONS FOR MTO ROAD SAFETY RESEARCH

2.1 Strategic Issues

2.1.1 The MTO may spend money on road safety research. Our task is to propose a programme of research for the Ministry. It is therefore important to present a coherent vision of the manner in which the conduct of research on road safety can be of use to the MTO.

2.1.2 Some believe that doing research will somehow automatically bring about better road safety management. This is obviously untrue and action on this erroneous belief is a prescription for waste. People of experience recognize that in many cases research has no discernible effect on action. It is therefore important to devote thought to the question of how to ensure that research resources are spent so that they support better road safety management, more efficient transport investment and less liability exposure.

For the immediate future one may need to know what topic to research first and which next. However, an orderly research plan is not primarily a list of priorities. To ensure that research is useful it needs to be viewed as a component of a knowledge-based system of road safety management. Only when research results are needed in order to perform some specific tasks within the MTO, is there a good chance that they will be used.

2.1.3 Research on road safety is not only the invention of new devices or countermeasures. In broad terms, research produces knowledge which enables professionals to manage road safety so that they can foresee the consequences of their decisions. Research extends from the simple and cheap assembly and assessment of published information at one end of the spectrum to the complex and costly collection and analysis of data or even of new product development and testing on the other. So one has to decide where the MTO research emphasis should be. Furthermore, roads, vehicles and people across North America are quite similar and conclusions reached by others may apply to Ontario. Conversely research done in Ontario may be of use elsewhere. These observations raise the question of what kinds of road safety research should the MTO engage in and support and how to cooperate with others for mutual benefit.

2.1.4 It is useful to think of research as a manufacturing process the "product" of which is knowledge. This manufacturing process requires not only money to pay for manpower and materials. For the product

to be good, research manpower has to be well trained in the specialized task of doing research on road safety. The existence of an ongoing research programme has the potential to improve and expand the road safety research manpower in the Province. The question arises how should the MTO research programme be used so as to best contribute to the enhancement of the specialized manpower which will produce good knowledge for the money which MTO invests in research.

The product of research is not stored only in "final reports". It is one of the characteristics of research that the main repository of the knowledge generated are those who do the research and those who use its results. Thus, to preserve fruits of its investment in research, the MTO must ask how to maintain and use the specialized human capital of those who do research in road safety and those who make use of it.

2.1.5 We likened the conduct of research to a manufacturing process the product of which is knowledge and noted that this manufacturing process requires, among other things, skilled labour. In addition to skilled labour, research on road safety requires some basic infrastructure which consists of: data about accidents, data about roads, data about traffic and a library of research reports. The efficiency of research depends on this infrastructure. Thus, one must ask to what extent the existing data and library infrastructure meet the needs of research on road safety.

2.1.6 Several questions of strategic importance have been identified in paragraphs 1.2 to 1.5.

How to ensure that research resources are spent so that they support better road safety management.

What kinds of road safety research should the MTO engage in and support and how to cooperate with others for mutual benefit.

How should the MTO research programme be structured so as to best contribute to the enhancement of the specialized manpower to produce good knowledge for the money which MTO invests in research.

To what extent do the existing data and library infrastructure meet the needs of research on road safety.

The following sections are devoted to a discussion of these strategic questions.

2.2 **Rudiments of a Road Safety Management System**

2.2.1 Many MTO activities affect safety. We are concerned here with those activities which have to do with the building and maintenance of roads and with the control of traffic thereon. When one deals explicitly with the road safety consequences of such activities, one may speak of a Road Safety Management System.

Road safety has always been one of the responsibilities of transportation engineers. While many of our warrants, standards and design procedures are motivated by safety, it is seldom possible to tell by how much accidents will increase or decrease as a result of some engineering decision. Thus, at present, one can seldom deal with the road safety consequences of engineering decisions explicitly and for this reason we can not claim to now have in place a Road Safety Management System.

Interest in clearly articulated Road Safety Management Systems (RSMS) is only now emerging. Some transportation agencies are further on this road than others. Because an RSMS depends on the ability to foresee the safety consequences of various decisions, they depend on the availability of the requisite knowledge. The generator of knowledge is research. Thus, it is best to discuss the question of how to plan for research within the framework of its contribution to a Road Safety Management System.

2.2.2 Ideally, we should have a clear idea about the main features of an RSMS for Ontario before attempting to propose a program of research for the MTO. However, this question has not been explored so far and a detailed examination of what an RSMS for Ontario should look like is outside the scope of this project. Thus, we have to put the cart in front of the horse. Attempting to avoid major omissions and oversights, we have no choice but to speculate about the main features of a possible RSMS for Ontario. This we do below. However, even before doing so, one of the first research tasks can be already identified. It is to

> *I. prepare a Master Plan for an Ontario Road Safety Management System*[1].

[1] Research task descriptions will be in italics and numbered in roman numerals.

2.2.3 The occurrence of road accidents is an undesirable consequence of mobility. The frequency of accident occurrence, their severity and their adverse consequences can be to some extent influenced by a variety of activities which as a rule consume resources. Thus, the task at hand is one of efficient management in which costs and effects are in proper balance. The framework for such management we call a Road Safety Management System. An RSMS might consist of the following elements:

A. The gradual and continuing incorporation of explicit road safety considerations into road design, road maintenance and traffic control standards, warrants and design procedures.

B. The incorporation of explicit road safety considerations in decisions which MTO staff have to make and which are not covered by standards, warrants and design procedures.

C. The identification, diagnosis and remedy of sites or features of road design, road maintenance and traffic control which require modification or where modification is justified.

D. The establishment of a learning process to monitor what the safety consequences of various MTO actions and interventions have been.

E. The maintenance of an outlook for safety improvement and innovation.

This rudimentary set of elements of which a Road Safety Management System might consist allows us to speculate about the knowledge and research required to support each element.

2.3 Research in Support of an RSMS[2].

2.3.1 Element A: (The gradual and continuing incorporation of explicit road safety considerations into road design, road maintenance and traffic control standards, warrants and design procedures.) Over the years a great deal of research has been done and published about the safety effect of various road design and traffic control features. However, the results of past work are not easy to make use of. Before past research can be used for the explicit consideration of road safety consequences, three steps have to be completed. First, one has to

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[2] RSMS stands for Road Safety Management System.

identify and assemble what is known about a specific subject. This requires considerable effort. Second, one needs to assess what is relevant and what is valid. This requires considerable expertise. Third one has to judge the extent to which the conclusions apply to Ontario. This requires experience, judgement and linkage to "Element D" of section 2.3. In our experience, it takes 3 to 12 months to produce a report on a specific subject (safety effect of edge-lining, shoulder paving, etc.) at the investment of 2-3 man-months of work. Thus, one of the main tasks of research is

> *II. to carry out an ongoing process for the generation and updating of critical, integrated, state of the art reports on the safety effects and consequences of standards, warrants and design procedures in road design, maintenance and traffic control.*

We expect that when a report is generated, the established procedures of the Ontario RSMS will ensure that its conclusions are considered in terms possible modifications of existing standards, warrants or design practices to which these conclusions apply.

Should it turn out, that on some item existing knowledge is insufficient, and the acquisition of knowledge through data collection and analysis is cost effective, considerations will be given to the formulation and initiation of a research experiment (project). As is well known, the number of cost-effective research projects is sufficient to bankrupt the World Bank. Therefore, one has to select a subset from all cost-effective research projects. Thus, one of the functions of research is

> *III. to formulate research questions, assess the cost-effectiveness of the various possible research projects, to set priorities and to design the research experiments.*

As the research budget allows, research experiments will be carried out. Their results will become part of the learning process mentioned in Section 2.3 D and discussed later in section 3.4.

The eventual aim of the "gradual and continuing incorporation of explicit road safety considerations into

road design, road maintenance and traffic control" is a state of affairs in which a safety assessment becomes a routine part of an engineering road or traffic control design project just in the same manner as one includes in the project file a calculation of earthwork quantities, an estimate of capacity, or a projection of traffic volume. It is through this device that the safety of alternative design and actions can be considered. Thus, it is the task of research to

> *IV. develop applicable methods for the safety assessment of alternative road design and traffic control projects.*

2.3.2 Element B. (The incorporation of explicit road safety considerations in decisions which MTO staff have to make and which are not covered by existing standards, warrants and design procedures.) Occasionally MTO staff have to make decisions with potentially important safety repercussions but for which standards, warrants or accepted design procedures have not been adopted nor are their safety repercussions known. In such cases one has to seek out what knowledge, experience and opinions exists in other jurisdictions and pass this through the filter of one's own knowledge to produce a guidance document in time for the decision to be made, perhaps in a few weeks. In this case the task of research is

> *V. to produce in short order guidance statements about the potential safety consequences of the decision now on the agenda. These statements need to be based on the experience and opinions of others and on what general knowledge and understanding may be applicable.*

In this case, reliable knowledge of safety repercussions does not exist. If the issue at hand is sufficiently important so that the conduct of a research experiment is perhaps warranted, it should be placed into the hopper of research topics and considered under task III in section 3.1.

2.3.3 Element C: (The identification, diagnosis and remedy of sites or features of road design, road maintenance and traffic control which require modification or where modification may be justified.) It is useful to distinguish between research

required to support the activity aimed at the remedy of <u>sites</u> and research supporting the task of remedying <u>features</u>. Many procedures for the identification of "blackspots" now exist. These procedures are based on the use of historical accident and traffic data and on data about the physical features of the road or intersection. No new research by the MTO on methods of blackspot identification is needed now, except for maintaining an outlook for innovation under element E in section 2.3.

All blackspot identification procedures end up with a list of sites some of which really require remedy and some which are on the list by chance and do not require attention. The proportion of these "false positives" is often very high. When remedial work at such sites is undertaken, resources are used inefficiently. It seems therefore important to devote research attention to <u>diagnosis</u> - that phase of the process in which trained personnel visit the site, make some observations, examine existing data and come to an opinion as to whether the site or feature really requires remedial work and if yes, what it should be. Accordingly, an important element of a research programme is to

> *VI. develop practical field and office procedures for the safety diagnosis of specific sites.*

Perhaps more important than the rectification of blackspots is the task of identifying features of road design, maintenance and traffic control which are found in many locations and the modification of which may be justified. This activity requires the confluence of several research tasks.

Under Element A we call for a research function which will generate state of the art reports about the safety consequences of various existing standards, warrants and design procedures. In the course of doing so it may become clear that some practices of the past may need revision and, as a result, a program of upgrading or retrofitting may be considered. Under Element B a similar activity is considered for items not covered by existing standards, warrants and procedures. Element E to be introduced later speaks about research required to spot promising innovation.

Once a feature is identified as requiring attention, questions of cost and effect estimation arise. From the point of view of research, the problem now is of the "decision analysis" kind. One has to assess the merit of deciding on the basis of what is known and compare this to the merit of acquiring more information first. One has to have a firm foundation for economic analysis including items such as costs of time and of accidents by type and severity. Accordingly, the research programme should

VII. develop decision analysis tools and procedures to guide the process of decision making for the rectification of features and carry out the analysis as needed.

Identification and diagnosis are the precursors of remedial action. At present it is not common to follow up and find out what effect the remedial action has had. Nor is it possible to do so for each project separately. However, unless one learns from accumulated experience it is difficult to improve practice. This is the subject of the next section.

2.3.4 Element D. (The establishment of a learning process to monitor what the safety consequences of various MTO actions and interventions have been.) We noted earlier that there is a great deal of uniformity in roads, vehicles and people across North America and therefore Ontario has only a limited responsibility in the generation of new road-safety knowledge. This is why research performed in element A is important and will yield knowledge about the safety consequences of various decisions and intended actions. However, there is much that is unique about Ontario and therefore, the applicability to Ontario of knowledge generated elsewhere is often doubtful. In addition, a wide band of uncertainty surrounds much of what is known about road-safety. Therefore the MTO needs to rely on and exploit its rich experience in implementation to ascertain how its various actions and interventions have affected safety. Accordingly, one of the main tasks of research is to

VIII. establish an ongoing comprehensive process of reporting, supplementary data collection, effect estimation and evaluation for the purpose of obtaining ever more refined estimates of the safety effect of actions and interventions which the MTO undertakes or sponsors.

Element D is at the heart of the RSMS. One may anticipate that, given the state of the art, much of the factual information on which initial decisions have to be based will be inaccurate and imprecise. It is instances of implementation which are the main source of factual, Ontario-specific, information; it is organized research which can extract it when care is taken to collect relatively cheap data.

There are real impediments to the implementation of research task VIII. There are reasons for which it is

not urgent and often inconvenient to find out whether some action did or did not increase safety. The price of not implementing part VIII of the research programme is twofold. First, in terms of lives and injuries, some actions which degrade safety will be perpetuated while other actions which enhance safety will not be undertaken. Second, in terms of money, resources will be wasted on actions which are not cost-effective.

2.3.5 Element E. (The maintenance of an outlook for safety improvement and innovation.) Suggestions for improvement and innovation come from many quarters: the public and its elected representatives, from employees of the MTO, from transportation professionals and from road-safety researchers. Researchers are in a unique position to engage in innovation initiatives since it is their job to read the literature and to mingle with road-safety professionals around the world. Researchers also can use their experience and knowledge to separate the wheat from the chaff. It follows that an important research function is

> *IX. to spot promising innovation initiatives and to express opinions about the merit of innovations suggested to the MTO.*

2.4 **Research Infrastructure**

In sections 2.1.4 and 2.1.5, we mentioned two principal items of research infrastructure (human capital and data) and an ancillary one (safety research library). All three are needed to produce good road-safety research. Therefore, when the MTO plans to spend money on research it must give thought to the infrastructure as well.

2.4.1 Human Capital.

Not many in Ontario do road-safety research and even fewer specialize in this field. Yet, as in any other endeavour, one can not expect competence without specialization. Thus, the infusion of some research money can be used to:

a. Broaden the circle of those who do road safety research and to
b. Allow the growth of expertise in research about road-safety.

Objectives a and b are in part contradictory. If many share a limited pie, none will be able to specialize and accumulate expertise. Perhaps the best strategy is to <u>strive to attract to research promising new talent gradually while consistently encouraging those who show good performance.</u>

Only part of the research product is embodied in the final report. Another part remains with those who wrote it in the form of understanding and expertise. The MTO cannot afford to employ experts in all specialized fields. It now employs few who are experts in road safety. Therefore, it is in the best interest of the MTO to find ways <u>to use for purposes other than research the expertise which its support of road-safety research will generate.</u>

The knowledge from research bears fruit only when it affects decisions or actions. In this sense, the research community is incomplete without its implementing counterparts within MTO. Accordingly, research and its implementation would benefit from the existence of a meeting ground of researchers and MTO counterparts, perhaps at an <u>Annual Forum for the Discussion of Road Safety Research in Ontario.</u>

It is a fact of life that people change jobs, move, or retire. For road safety management this is a loss of human capital which is difficult to prevent. The existence of a recognizable community of road safety workers with occasional new entrants and a network of personal ties can diminish the gravity of the loss. The MTO research programme in road safety and its RSMS (when it materializes) can <u>seek ways to establish and maintain such a community.</u>

2.4.2 <u>Data.</u>

There is not much road safety research which can be done without data. There is also not much road-safety management which can be done without the same data. As a matter of fact, if safety is to be a factor in the planning of future investment or in the conduct of daily business, the absence of basic data renders rational management exceedingly difficult. One can not know how important some action is, if one does not know how many (target) accidents it may affect. One cannot determine the number of target accidents if it is not possible to link the accident file and the road inventory file. One cannot find if a site is unduly hazardous if there is no information about accidents and traffic flow etc. In short, research is no more than speculation if it is not rooted in data. Management is deprived of the basis on which to make cost-effective decisions.

Other transportation agencies found it possible to create and maintain linked data bases. It is difficult to

see a reason (other than lack of budgetary allocation) which would prevent Ontario from doing the same. It is important to remember that by not having adequate linked data bases, cost-effective management becomes difficult (if not impossible). Thus reluctance to invest in adequate data is most likely very costly in real terms. A great deal of effort goes into the generation of accident reports by the police. This is a precious and costly resource which is at present difficult to make use of for want of comparatively negligible resources.

2.4.3 Repository and Library.

An important part of road-safety research for Ontario is the assembly and assessment of results published by others. Those who have done this will know that the task is far from trivial. Research results are published in many journals or as technical reports and are seldom found or catalogued in general-purpose libraries. Yet, we find, that once assembled, the material tends to be used again and again. In short, the MTO would be well served if there was in existence a library specializing in matters of road safety. Nowadays it is not necessary to think of a library as a single physical location. It is perfectly feasible to have many holdings at different places as long as some organizational and clerical effort is invested in the maintenance of files and networking.

We spoke earlier of a community of road safety workers. The establishment of a safety reference library network would be one aspect of such a community.

Those who lived long enough recognize that a great deal of wheel reinventing is going on. Not many recall the research reports written 10 years ago, and even fewer know where to find them. Yet the many questions which these reports dealt with are still with us. It therefore makes good sense to have a repository of road-safety related reports generated in Ontario.

2.5 Closure

It is important to do research into road-safety because this makes for better road safety management. To get started, one has to ask what should be done first and what next. However, if the MTO plans a continuing commitment to knowledge-based road safety management, one has to approach the management of a road-safety research programme with a bit more deliberation. This report is an initial attempt to do so.

3. PRIORITIES FOR ROADWAY SAFETY RESEARCH

The strategic directions proposed in Section 2 have set the framework against which specific research recommendations will be put forward. These recommendations, which are set out in this section (3), are in two categories:

1. Research on roadway elements

2. Basic research

Recommendations in the first category are in the form of a prioritized list of elements that need to be researched. In the second category, basic research that is needed to facilitate and supplement research on roadway elements is identified.

3.1 Research on Roadway Elements

3.1.1 Prioritization Procedure

Research is of value if it is likely to improve decision-making or actions. Thus, in assessing what research might be undertaken, and in prioritizing research programmes, it is necessary to identify the decisions on roadway elements that could be affected by research programmes under consideration, to give a preliminary assessment of whether the research is likely to lead to better decisions, and to judge whether improved decision-making is likely to yield safety gains. The process of prioritizing roadway safety research programmes could then be seen as seeking answers to a sequence of three questions on each element of interest:

> (a) Is there enough knowledge on safety repercussions of a decision to enable it to be properly made? In effect, is the knowledge sufficient to enable a review of the adequacy of MTO policy, and, if necessary, a revision of the policy? If the knowledge exists and is adequate, then further research is unnecessary.

(b) If research is necessary, is it worthwhile?

(c) If research is necessary and worthwhile, what priority should the research take?

Elements were eliminated after the first two questions if one of three main criteria were met. These are: (a) the element does not fit the profile of what roadway safety research is aimed at; (b) the element was not strictly of relevance to roads under MTO jurisdiction; (c) there was insufficient information to enable prioritization. The latter was the case for rock cuts, but an additional factor was the fact that a research project had already commenced on this element. In Table 3.1, those elements omitted from further consideration are listed along with the reason for omission. Note that in some cases the omitted element now forms a combined research programme with another original element.

The initial screening of elements left a total of 16 research programmes to be prioritized. These are identified in Table 3.2 along with the number of the applicable safety assessment in Appendix A and an assigned research programme number.

TABLE 3.1: LIST OF ELIMINATED ISSUES/ELEMENTS

Element number and element	Reason for omitting*
1.8 Rock cuts	(c)
1.9 Gore areas	(c)
2.1 Vertical curves and gradient	Part of climbing lanes
2.3 (No)passing zones/sight distance	Part of passing lanes
3.4 Abandoned vehicles and trash	(c)
3.5 Mail boxes	(c)
3.6 Curbs	(c)
4.2 Prohibitions	(a)
4.3 Speed control	(a)
4.4 Signing and marking	(a)
5.3 Intersection sight distance	(b)
5.4 Pedestrian accommodation	(b)
5.5 Channelization	Part of turn lanes
5.6 Tapers	(c)
5.7 Turning radii	(c)
6.1 Railroad crossings	(b)
6.3 Bicycle paths	(c)
6.4 Billboards	(c)
6.5 Wildlife	(c)

* (a) does not fit the profile of roadway safety research
(b) not strictly of relevance to roads under MTO jurisdiction
(c) insufficient information for prioritization

TABLE 3.2: RESEARCH PROGRAMMES TO BE PRIORITIZED

Decision	Research Programme No.	Safety Assessment No.
on shoulder width, type	1	2
on lane width	1	2
to install a traffic signal	2	15
on traffic signal elements	2	16
to install embankment guiderail	3	14
on side-slope ratio	3	14
to install a left-turn lane	4	10
on where to install a climbing lane	5	4
on where to install a passing lane	6	5
on where to install roadway lighting	7	8
on design of roadway lighting	7	8
to install intersection lighting	8	1
on where to re-surface for safety	9	17
to install median barriers	10	11
on median design	10	11
on utility poles, signs posts	11	6
on location and protection of trees	12	7
on access frequency	13	3
on treatment of narrow bridges	14	13
on treatment of drainage structures	15	12
on horizontal curvature design	16	9

At the heart of the procedure to prioritize these programmes is a weighted matrix methodology similar to the goals-achievement matrices used in transportation planning. While this procedure is necessarily subjective, it's use can be rationalized on the basis of the substantial precedence in transportation decision-making applications particularly, as was the case for this project, where there are time and budget constraints.

The development and workings of the prioritization procedure can be described as a sequence of steps:

1. A set of criteria were developed against which each research programme would be assigned a score according to how well it "measures up" to each criterion.

2. Each criterion was assigned a weight in accordance with its perceived importance relative to the other criteria. In effect, this was done by assigning maximum research programme scores for each criteria. The criteria and maximum scores assigned are shown in Table 3.3.

3. Programmes were rank ordered for each criterion and then assigned relative scores not exceeding the maximum for each criterion.

4. Each programme was assigned a probability of research improving safety knowledge and MTO decision-making.

5. Scores were summed for each programme and each sum was then adjusted by multiplying it by the probability assigned in step 4.

6. Research programmes were ranked according to the final scores and then four groups of priorities were assembled with roughly equal numbers of programmes at each priority level. This resulted in the following ranges:

Priority 1 (High)	> 50
Priority 2	44-50
Priority 3	40-43
Priority 4	< 40

7. Sensitivity analysis was performed by using a Monte Carlo type simulation procedure whereby criteria weights and programme scores were allowed to vary at random within a specified range, assuming that

each value in a range was equally likely. Ranges varied from +/- 5 of the expected value for small scores to +/-10 for large scores, subject to each score not exceeding the maximum. For each programme, the distribution of scores after 1,000 simulations gives an indication of the certainty with which the programme fits into the assigned group. The measure of this certainty is the percentage of simulated scores that fall into the range of scores for each priority group.

TABLE 3.3: EVALUATION CRITERIA AND MAXIMUM SCORES

CRITERIA	MAXIMUM SCORE Expected	Range
A. Target accidents	30	20-40
B. Research cost and difficulty	20	10-30
C. Potential for saving accidents by implementation of research results	50	40-60

3.1.2 Results

The programme weighting matrix for the 16 programmes subjected to the prioritization procedure is shown in Table 3.4. The results of the sensitivity analysis simulation are shown in Table 3.5 which shows the programmes in each of the four priority groups.

Specific description of research programmes is left open at this point and should be formulated by MTO on the basis of the safety assessments related to the research programmes (Appendix A). The reason for this is that the list of safety assessments is neither comprehensive and there may well be other aspects of a potential research programme that are to be assessed in the near future.

Before moving on, it is worthwhile to point out that the priority ranking process should not be regarded as firm or static in time. There are four reasons for this:

(a) New elements might be added to the list.

(b) As more information, e.g., accident data or field experience, becomes available, programme scores might be revised and priorities reassigned.

(c) MTO might choose to adjust the programme scores or criteria weights after a carrying out a more rigorous exercise to determine what these should be. In response to an earlier draft of this report, a Delphi procedure, using experts within and outside MTO has been suggested.

(d) MTO might find it worthwhile to use a more sophisticated approach, e.g., along the lines of the multiple criteria modelling research recently done for MTO (3.1).

TABLE 3.4: PROGRAMME WEIGHTING MATRIX

Research Programme[1]	Programme Scores for Criterion[2] A (Max.30)	B (Max.20)	C (Max.50)	Total Score (100)	Probability Adjustment[3]	Adjusted Score	Rank
1	20	10	40	70	0.8	56	1
2	15	10	30	55	0.9	50	4
3	20	10	30	60	0.9	54	3
4	10	15	30	55	0.9	50	4
5	10	15	25	50	0.8	40	9
6	15	15	20	50	0.8	40	9
7	20	15	35	70	0.8	56	1
8	10	15	20	45	0.9	40	9
9	15	15	30	60	0.8	48	7
10	10	15	25	50	0.8	40	9
11	5	15	20	40	0.8	32	13
12	5	15	20	40	0.8	32	13
13	10	15	30	55	0.9	50	4
14	5	15	15	35	0.8	29	15
15	5	15	15	35	0.8	29	15
16	15	10	30	55	0.8	44	8

1 - Research programmes are identified in Table 3.2 and 3.5.

2 - Evaluation criteria are identified in Table 3.3.

3 - Probability of research improving safety knowledge and MTO decision-making.

TABLE 3.5: PRIORITY GROUPINGS FOR ROADWAY SAFETY PROGRAMMES

Programme Number	Programme Title (In brief)	Priority	% chance of priority being 1	2-3	4
1	Lanes and shoulders	1	81	18	1
3	Guiderail and side-slopes	1	76	24	0
7	Roadway illumination/night visibility	1	88	12	0
2	Traffic control signals	2	42	53	5
4	Left-turn lanes	2	42	53	5
9	Resurfacing/skid resistance	2	43	52	5
13	Access control	2	42	53	5
16	Horizontal curvature	2	24	56	20
5	Climbing lanes	3	4	60	36
6	Passing lanes	3	4	60	36
8	Intersection lighting	3	6	60	34
10	Medians and median barriers	3	5	60	35
11	Poles and posts	4	0	10	90
12	Location and protection of trees	4	0	10	90
14	Narrow bridges	4	0	3	97
15	Drainage structures	4	0	3	97

3.1.3 **Elements of a research programme**

Following guidelines set out under strategic directions addressed in Section 2, it is useful to summarize how a typical research programme might ideally be shaped by identifying and listing some basic elements. To illustrate what we propose, a roadway illumination research programme is used as an example. On the basis of the safety assessment (Appendix A) for this element, there are two practical questions for MTO:

a) Whether more of the road network should be illuminated, and if so, where, i.e., are present warrants or guidelines adequate?

b) What standard of illumination is appropriate?

To answer these questions requires that a research programme in the form of a series of linked studies be embarked on.

(1) First, a detailed state-of-the-art appraisal of this specific question has to be produced (or extracted from other recent appraisals). As suggested in Section 2, this task might require two to three man-months of effort for each programme of interest. On the basis of this appraisal, it is necessary to try to guesstimate (separately for illuminating and for increasing the standard of illumination) what is the expected change in accident frequency and severity, in speed, and perhaps in driver comfort, and how accurate all of these estimates are.

(2) Second, a decision analytic study should be undertaken. The procedure for conducting such a study is outlined and illustrated in a recent Transport Canada report (**3.2**) that illustrates the process for research on day-time running lights. In essence the study addresses two questions: (i) Is what we know accurate enough to reach a decision and if so what should the decision be? (ii) Is more research needed and is it feasible?

(3) To undertake a decision analytic study, it would be necessary to obtain Ontario specific "accident costs". These need to be known by accident severity and type, by road environment (urban/rural), by light condition (day/night) and so on. It is also necessary to have a feel for the degree of accident under-reporting by accident type and severity. To produce these Ontario-specific accident costs and estimates of under-reporting may be a third element of a research programme. This element is listed under "basic"

research in the next sub-section since it is common to all roadway elements.

(4) Should it turn out that a decision should not be made on the basis of what is known at the time of the research, and that a study of Ontario experience with illumination would be of benefit, the design and execution of such a study may be a fourth element of a research programme.

(5) To do before-and-after follow-up may be the fifth element. However, this element is also listed under basic research since it is properly part and parcel of an on-going and separate programme of estimating the safety effect of roadway changes that the MTO is responsible for.

3.2 **Basic Research**

We have, in the course of this report, alluded to a number of basic research projects that need to be undertaken in advance of, or at least concurrently with, programmes identified above under roadway safety research. Below, is a summary of basic research elements that appear vital to the successful undertaking of these programmes. The identification of these elements arose partly from considerations discussed under strategic directions and partly from our experience in trying to use Ontario data to do safety research, especially the development of accident profiles attempted for this project. Some of the elements identified below might be classified as action rather than research. If the semantics are important, one can regard these elements as basic research needs.

(1) **Prepare a master plan for an Ontario Road Safety Management System (RSMS)**. This should entail: **(a)** a review of the present thinking about RSMS in the FHWA and some key States; **(b)** a review of the systems and elements now in place in key States and how well they work; **(c)** formulation of a few options for Ontario and the detailing of their main elements; and **(d)** an evaluation of what the organization, manpower, and cost needs are for each option and what the benefits might be.

(2) **Set up a before-and-after evaluation research programme.** The setting up of the programme requires a small study which might in turn identify research needs to facilitate such a programme. We envisage that a number of other basic research activities need to be undertaken to facilitate this and other research. These are identified under items 3 to 5 below.

(3) **Identify data needs for safety research.** Data needs for safety research must be identified and current data available should be reviewed against these needs. Based on our experience, we envisage that such a review would find a number of needs over and above what is currently available:

(a) The under-reporting of accidents needs to be examined for a variety of reasons, including the application to decision analytic studies proposed in Section 3.1.3 above.

(b) Data that should be routinely collected for before-and-after studies needs to be identified.

(c) For the long term, information collected on accident report forms might be reviewed for compatibility with safety research needs.

(d) The specification of inventory data routinely collected and stored in the Highway Inventory Management System (HIMS) database needs to be reviewed for compatibility with safety research requirements. For example, the database currently provides no information on artificial lighting, side slopes and embankment guiderail and little information on horizontal and vertical alignment.

(e) All obstacles to the linking of accident, traffic and inventory data-bases need to be removed and a linked database should be prepared annually. As described in Appendix B, limited success was achieved in linking the databases available for this project. To be more successful, the referencing systems of the 3 databases must be entirely compatible. To effectively use linked databases in a multi-year study requires that all information be coded to a constant referencing system regardless of changes that are made to this system from time to time.

(f) Basic to the effective management of roadway safety is the ready availability of accident profiles, such as those presented in Appendix B, that provide extensive tabulations of relevant accident information. The current Ontario Road Safety Annual Reports fall far short of fulfilling this need for a number of important reasons. Mainly, these reports are for accidents in the entire province, not just those on MTO roads; accident totals are not normalized for exposure; and there is very limited information on accidents associated with roadway elements. We recommend that accident profiles for roadway safety management be routinely produced on an annual basis.

(4) **Set up and embark on a programme of multivariate studies.** The aim would be to give estimates of what is expected in terms of safety as a function of causal and/or predictive variables. This type of

research has already started (**3.3**). The immediate use to MTO would be **(a)** to have a benchmark against which to judge the safety performance of various existing facilities (part of the idea in "blackspot" identification), **(b)** to have an idea of how different facilities (e.g., roads of differing features; intersections with different controls) perform in terms of safety, **(c)** to be the starting point of inquiries as to the causes of differences in safety as noted, and **(d)** to give preliminary assessments of the applicability to Ontario of multivariate studies done for other jurisdictions (e.g. safety assessment, Appendix A, reference (**A2.3**)).

(5) **Undertake a study of Ontario accident costs and under-reporting of accidents**. It is necessary to obtain Ontario specific "accident costs" for decision analytic studies referred to in Section 3.1.3 and, generally for all decision-making on cost-effectiveness of improvements that affect safety. As mentioned, these costs need to be known by accident severity and type, by road environment (urban/rural), by light condition (day/night) and so on.

REFERENCES (Section 3)

3.1 Kazakov A., Cooke W. and Y. Roll, "Measurement of Highway Maintenance Patrol Efficiency: Model and Factors". Transportation Research Record 1216, pp.39-45, 1989.

3.2 Hauer E, Lovell J. and B. Persaud, "New Directions for Learning about Safety Effectiveness". FHWA, NHTSA and Transport Canada Report FHWA/RD-86-015, 1986.

3.3 Persaud B.N., "Blackspot Identification and Treatment Evaluation". MTO Report TDS-90-04, November 1990.

4. RESEARCH PRIORITIES AND PROGRAMMES ELSEWHERE

4.1 Introduction

With respect to the priorities identified in Sections 2 and 3 for MTO roadway safety research, the question arises as to how the recommended programme stacks up against what others have identified as roadway safety research needs. This section addresses this question which, in the context of the recommended programme, can be split into three components:

(a) What is the structure of formal roadway safety research programmes in other jurisdictions?

(b) What elements of roadway safety research have been identified as priorities elsewhere?

(c) What elements are currently being researched and will the MTO research programme, if carried out fully, duplicate research being done elsewhere?

To address these questions comprehensively is an impossible task. What we have done instead is to try to extract the flavour of what of relevance is going on elsewhere mainly by reviewing recent materials put out by a number of important North American agencies. These are as follows:

- Transportation Research Board (TRB)
- American Association of State Highway and Transportation Officials (AASHTO)
- U.S. Department of Transportation, Federal Highway Administration (FHWA)
- American Society of Civil Engineers (ASCE)
- Institute of Transportation Engineers (ITE)
- California Department of Transportation (Caltrans)
- Transport Canada
- Transportation Association of Canada (TAC)

The information from each of the agencies identified is reviewed below in the light of the research recommendations in this report. This is followed by a closure that provides a brief overall assessment of how the programme recommended to MTO stacks up against what others are doing. From the onset, three points which should be borne in mind by the reader require emphasis.

(i) Direct comparison of the recommended programme with other programmes is difficult because other agencies have tended to look at research needs for road safety in general, including driver and vehicle safety issues, while this project was concentrated on roadway safety elements and associated research needs.

(ii) In attempting to separately address each agency's perspective there is necessarily some overlap caused by the considerable interaction among the various agencies and a tendency for aspects of all three questions raised above to be addressed simultaneously.

(iii) In assessing the relevance of findings of national U.S. agencies to Ontario, one must keep in mind that their target is a nation with a more centralized form of government than Ontario has. Nevertheless, much of what is the responsibility of the Federal government in the U.S. is within the jurisdiction of a Province in Canada. Thus, what is going on at both the State and Federal levels in the U.S. is of relevance.

4.2 **Priorities and Programmes of Other Agencies**

4.2.1 Transportation Research Board (TRB)

TRB has, in recent years put out a number of important documents which relate to safety research priorities. Aspects that are relevant to this project are summarized below, followed by an attempt to extract some sense of direction from information in these TRB sources.

(i) Committee for the Study of Geometric Design Standards for Highway Improvements

This committee, on behalf of FHWA, studied the cost-effectiveness of geometric design standards for resurfacing, restoration and rehabilitation (RRR) projects. TRB Special Report 214 (**4.1**), which resulted from that study, has been referred to in this report in many of the research summaries on safety of roadway elements.

An aspect of Special Report 214 that is of interest in this Section is the findings and recommendations on safety research and training needs. Noting that "despite more than one-half century of modern road

building, knowledge of the safety consequences of highway design decisions is limited" and that "designers often lack the capability or time to apply the existing knowledge", the committee made four key recommendations on safety research and training:

(a) that a task force be set up to assess highway safety engineering needs and to establish research, education and funding priorities. This task force has been set up and, later in this section, their work to date is reviewed.

(b) that FHWA develop, distribute, and periodically update a compendium that reports the most probable safety effects of improvements to design features. The committee saw the contents as possibly including:

- background information on the use of accident data and models to estimate safety effectiveness of design improvements,

- Easy-to-apply procedures for estimating safety effectiveness, and,

- procedures for using the estimates of safety effectiveness in cost-effectiveness analysis for design improvements.

As noted in the section covering FHWA initiatives, work on the compendium is underway. While such a compendium would be useful to MTO it would still be necessary for MTO to do whatever research is necessary to adapt the contents to MTO's needs and conditions and to narrow those gaps in knowledge that are vital to Ontario's needs. In this regard, the committee pointed out that the compendium should help redirect current research efforts since major sponsors of research will be able to identify the principal gaps in current knowledge and to determine where research might be able to fill in those gaps. In many ways, this research project has fulfilled that aspect of the compendium's role from the perspective of MTO.

(c) that FHWA and NCHRP (National Cooperative Highway Research Programme) should increase research on the relationships between safety and highway design. In this light, the committee commented that previous and current research efforts, as a rule, "lack the statistical controls necessary to develop relationships that can be reliably transferred to other locations". [It is worth pointing out here that this

statement lends support to many of the safety assessments in this report.] Under this recommendation, the committee felt that topics that especially merit further research include:

- Safety effect of physical and operational features of intersections,

- Safety effects of lane and shoulder conditions on urban highways and streets,

- Safety effects of different sideslope and other roadside conditions,

- Safety effect of various low-cost safety treatments such as warning devices at hazardous locations or shoulder widening at horizontal curves, and

- Combined safety effects of changes in horizontal and vertical alignment.

(d) that the various highway agencies should support training activities to keep design engineers abreast of safety conscious design. This recommendation appears to be in harmony with many of the recommendations on strategic directions in Section 2.

(ii) <u>Standing Committee on Research Needs</u>

This committee co-ordinated an effort among TRB technical committees to develop and prepare research problem statements (**4.2**). The 25 problem statements on the subjects relevant to roadway safety are listed in Table 4.1 along with the priority recommended by the committee. It can be seen that the research programme recommended to MTO is quite in line with what the TRB committee sees as roadway safety research needs.

Table 4.1: Highway Safety Research Problem Statements in Circular 363

HIGH PRIORITY
Operational and Safety Effects of Reduced Lane and Shoulder Widths on Urban Freeways
Evaluation of Substandard Stopping Sight Distances on Existing Highways
Passing Behaviour on Two-Lane Rural Highways
Risk Assessment of Highway Geometric Design Features
Highway Sight Distance Requirements
Critique of AASHTO's Superelevation Criteria
Handbook of Geometric Design Consistency
Trade-off Between Roadway Width and Foreslopes on Two-Lane Rural Highways
Clear Recovery Zones
Guidelines for Upgrading Highway Safety Features and for Maintenance Operations
MODERATE OR UNASSIGNED PRIORITY
Geometric Design for the Impaired Driver
Truck Dynamics Contribution to Rollover by Tight Curves
Operational and Safety Effects of Offset Left-Turn Lanes
Driveway Intersection Sight Distance Requirements
Meeting the Clear-Zone Requirement on Non-Limited Access Controlled Highways
Optimum Spacing of Crossovers on Divided Dual Lane Highways
Operational and Safety Effects of Median Acceleration Lanes at Highway T Intersections
Barrier Warrants for Embankments
Determination of Impact Severity Values for B/C Analyses
Safety Treatment of Parallel Drainage Structures and Roadside Ditches
Field Study of Roadside Safety to Collect Data for B/C Analyses
Compilation and Dissemination of the Results of Research on Highway Safety Devices
Vehicle/Highway Safety-Interface Design
Standard Drawing Review for Highway Safety Designs
Design Guidelines for Identifying and Correcting Operating Speed Inconsistencies in Horizontal Alignment on Two-Lane Rural Highways

(iii) TRB Special Report 229(**4.3**)

A committee of experts convened by TRB contemplated the strategic issues associated with research on road safety and published their findings in a TRB Special Report, prior to a presentation at the January 1991 Annual TRB Meeting. What follows is a review of those findings which we think are relevant to MTO.

Research is said to contribute to the delivery of road safety by identifying, developing and evaluating interventions to guide safety programmes and investments. The presently inadequate, declining and sporadic funding makes it difficult to focus on longer term research. As a result, few researchers are attracted and those who do stay long enough to develop expertise often leave for greener pastures.

The committee noted that there are gaps in current research which have adverse economic consequences. First, safety motivated standards have large costs but there is often insufficient knowledge about their safety merit. While the TRB report illustrates this by vehicle standards, one could use highway design standards to show the same. Thus, e.g., it can be very costly to comply with sight distance standards while the safety benefit of doing so is unknown. Second, gaps of knowledge are said to lead to lost opportunities. According to the committee, "...highway agencies miss opportunities for safety improvements or make safety improvements that are not cost effective" (p.6). In short, to avoid having to make decisions without being able to anticipate their safety repercussions, one needs to invest in research on an ongoing basis.

The committee identified six principal "Topics for Future Research".

1. Crash avoidance; aimed mainly at diminishing the role of human errors as a factor in crashes through human factors research.

2. Occupant protection; aiming to develop a scientific basis for the safety engineering of vehicles.

3. Highway safety design and operation; where more needs to be known about the safety benefits of alternative highway design and traffic engineering improvements.

4. Postcrash acute care and rehabilitation.

5. Management of highway safety; to find better methods for driver licensing, vehicle inspection, traffic law enforcement, etc.

6. Driver information and vehicle control technologies; aimed at reaping the benefits new technology has to offer for road safety and avoiding its potential for degrading safety.

The committee noted that adequate funding of research is essential but that there are several other strategic issues which merit equal attention: that research be long-term in nature; that it be of high quality; and that innovation be stimulated. It also noted that the U.S. Department of Transportation has an imperfect record of supporting quality research, of nurturing a core of scientific researchers and of doing long-term research in a political environment. Even so, it recommends that the FHWA and NHTSA remain the principal agencies receiving research funding, hoping for a climate "more conducive to new ideas and new approaches". In addition, the committee recommends the establishment of research centers at universities and other research institutions and graduate programmes to train new researchers in highway safety. It also recommends that proposals and findings be subject to peer review and that unsolicited proposals be encouraged.

(iv) National Cooperative Highway Research Program (NCHRP)

The NCHRP was established in 1962 to provide a continuing program of highway research, similar to the role of MTO's R&D Branch. It is sponsored by members of AASHTO in cooperation with FHWA who, each year, initiate the programme by identifying critical problems. Thus, projects currently underway or recently completed provide a feel for what is currently topical in the U.S. A recent NCHRP summary of projects (**4.4**) was used to identify current or recent NCHRP sponsored research projects that address issues relevant to roadway safety.

Project	Title	Status
2-16	Relationships between Vehicle Configurations and Highway Design	Complete
3-38(5)	Effective Utilization of Street Width on Urban Arterials	Complete
3-42	Determination of Stopping Sight Distances	Pending
3-43	Use of Shoulders or Narrow Lanes to Increase Freeway Capacity	Pending
15-12	Roadway Widths for Low Traffic Volume Roads	Current
22-5A	Warrants for the Installation of Low Service Level Guiderail	Current
22-7	Update "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances"	Current
22-9	Improved Procedures for Cost-Effectiveness Analysis of Roadside Safety Features	Pending
22-10	Updated Materials for a Traffic Barrier Hardware Guide	Pending

4.2.2 American Association of State Highway and Transportation Officials (AASHTO)

Discussions among AASHTO, TRB, FHWA and NHTSA resulted in identification 19 specific safety strategies (**4.5**) for improving U.S. highway safety. These strategies were then framed into ten major areas of recommendation listed below.

Recommendation Category	% of funds
Safe Driving Performance	20%
Improved Pedestrian Safety	3%
Corridor Safety Improvements	14%
Improved Highway Safety	34%
Enhanced Vehicle Safety	3%
Safe Commercial Motor Vehicle Operations	7%
Vehicle Crash Avoidance	7%
Enhanced Rural Emergency Medical Services	7%
Strategic Research for Safety	3%
Safety Management	2%

Of particular relevance to the programme recommended to MTO are recommendations in three areas: (i) improved highway safety, which incorporate strategies for night accidents and high accident locations; (ii) safety management, which incorporates strategies for traffic safety information resources, and the training and development of safety managers; and (iii) strategic research for safety, which, to a large extent, has been addressed by the TRB committee that recently prepared Special Report 229 reviewed in Section 4.2.1 above.

Another AASHTO report (**4.6**), this time by a Task Force on Post-1991 Research, briefly addressed safety research needs. They alluded to two main areas for concern:

(i) The practice of roadway design or redesign as a sequential process, with safety considered after the

geometric features are selected.

(ii) The compounding problem of lack of reliable accident reduction factors to allow a systematic analysis of the economic balance between design elements and probable safety benefits.

In the second case, the Task Force recommended that a research programme in this area should:

- Identify critical problem areas through analysis of accident trends and data.

- Establish relationships between highway design features and accidents.

- Develop procedures for evaluating safety cost effectiveness of design alternatives.

- Establish a system for concurrently evaluating the safety impacts of roadway and roadside design phases.

The similarity of this recommendation with the overall MTO research programme is striking. The first aspect -- identify critical problem areas .. -- has formed the principal objective of this project, while the other three aspects broadly encompass most of the major recommendations made in this report.

4.2.3 Federal Highway Administration (FHWA)

FHWA is involved in a number of safety research initiatives, many of which have already been mentioned as cooperative efforts with TRB and AASHTO. Specific FHWA research projects of relevance are mentioned in the annual progress report of the Nationally Coordinated Program (NCP) of Highway Research, Development, and Technology (**4.7**), a management framework for FHWA's highway research, including initiatives carried out through NCHRP and others. The NCP has identified the following high priority National programme areas for highway safety research for 1988-1990.

- Developing Performance Specifications for Retroreflective Devices
- Highway Safety Design Practices and Criteria
- Truck-Highway Safety

- Information Systems
- Work Zone Traffic Control

Specific NCP projects of relevance are identified below under various status headings.

Significant results in the past year (ending September 1990) include:

.. the completion of a "Highway Safety Information System" (HSIS) consisting of merged accident, roadway and traffic files from 5 states, along with the ability to compute accident rates.

.. development of safety analysis methodology (similar to that currently being recommended to MTO).

.. development of a method, "Design/Risk Analysis", for determining the cost-effectiveness of design decisions or exceptions which considers accident reduction as well as an operational assessment.

.. the completion of work on a synthesis report on highway lighting, documenting research since 1982.

Work underway includes:

.. a study to examine the possible movement of accidents from improved to non-improved sites

.. a joint funded study with NHTSA to identify safety research priorities for the 1990's.

.. "Development of Roadside Accident Data Collection and Analysis Plan" has initiated the process of identifying and prioritizing roadside safety issues to be addressed in an accident study.

.. "Compendium of the Safety Effectiveness of Highway Design Features" has completed critical reviews of some 170 identified references which document previous research on highway safety in geometric design. References cover alignment, cross-section, access control, intersections, interchanges, and special facilities. [**Comment:** This effort is apparently the result of a recommendation in TRB Special Report 214 reviewed in Section 4.2.1. When the compendium is published, it would be of interest to scrutinize the results in the light of the recommendations in this report.]

Planned starts for FY91 include:

.. "Economic Analysis of Highway Safety Data for the Nineties" will review the sources, uses and costs to obtain traffic data.

.. "Emerging Technologies for Improving Safety Data and Analyses" will assess the potential of new and emerging technologies to obtain higher quality accident data at lower cost.

.. "Prevention of Single Vehicle Run-Off-Road Accidents" will evaluate current methods to prevent these accidents.

.. "Selection Criteria for Left-Turn Phasing, Indication Sequence, and Auxiliary Sign" will study traffic operations at 480 intersections.

.. "Potential Safety Implications of Advanced Technology" will develop the basis for the FHWA post-1992 safety research programme.

.. "Development of Preliminary Severity Indices for Roadside Benefit/Cost Model".

.. "State-of-the-Practice: Geometric Design Consistency".

Reports soon to be published include:

.. a technical article on the HSIS median crossover analysis

.. a report on strategic transportation research for highway safety

.. "Variable Speed Limit System for Freeways" (with software and hardware documentation)

.. "Assessment of Current Speed Zone Criteria"

.. "Effect of Raising and Lowering Speed Limits on Speed and Accidents"

4.2.4 American Society of Civil Engineers (ASCE)

In the proceedings of a major ASCE conference, (**4.8**) there are a number of references to current and future safety research needs in general. Of relevance to roadway safety research issues covered in this report are portions of two papers in the proceedings.

Richard Powers of FHWA ("Safety on 21st century highways") argues that to further enhance roadside safety, four major elements must be recognized and addressed. In order of priority, these are: (i) the roadside itself, i.e.cut/fill slopes, embankment geometry, and slope uniformity; (ii) drainage treatment, i.e., culverts, ditches and berms; (iii) roadside hardware, e.g., sign and luminaire supports; (iv) the selection and use of traffic barriers. In the paper there was little evidence presented in support of this priority list.

Timothy Neuman, a consultant ("Safety and Operations Related to Geometrics of 21st Century Highways") suggests that "despite years of research effort, many of our basic design standards remain unchanged from the 1940's". He proposes that a "concentrated effort must be undertaken to critically evaluate basic highway design standards to ensure their reasonableness regarding safety and operational cost effectiveness". It is worth noting that these statements would appear to lend support to the recommendations for roadway safety research contained in this report. As examples of design values which the author believes should be reconsidered, the following are cited for 2-lane roads: lane and shoulder width; stopping sight distance; for horizontal curves: greater clear zones, flatter side slopes, alignment revision, increased pavement friction and increased superelevation. For freeways the author suggests considering the effects of: implementing the full AASHTO values of lane and shoulder width instead of the usual design compromises; eliminating left-hand entrance ramps; adhering to proper ramp spacing controls; and eliminating weaving sections.

4.2.5 Institute of Transportation Engineers (ITE)

To our knowledge, the Institute apparently has not put out a comprehensive safety research needs statement but ITE's recognition of the importance of road safety research is evidenced in a few recent publications. We have not, in this report, attempted to assemble these diverse statements since, on the surface, the thrust appears to correspond closely with that in statements put out by others.

One ITE document that might be considered unique and relevant to this project is an informational report (**4.9**) titled "Safety Programs and Their Effect on Highway Standards" prepared by Technical Committee

5B-10. The report was based on a project that surveyed U.S. highway agencies on various issues related to the title.

Among the issues addressed was the influence of safety programmes on safety analysis and research. The responses suggest that almost all of the local and federal agencies and about one-half of the state agencies do not have a formal process to review design standards for safety purposes and thus rely on others, (e.g., FHWA, TRB, AASHTO, NCHRP) to assess the influence of their design standards on highway safety. The committee, noting that the responses reflect a notion that agencies view standards as the safety process, felt that "the responses did not acknowledge that nationally recognized standards or guidelines are not universally acceptable nor are they static and therefore subject to new findings that modify application and/or may be more appropriate under varying conditions". This appears to be a call for agencies like MTO to embark on safety research programmes of the type recommended in this report.

4.2.6 California Department of Transportation (Caltrans)

The comments below are based on impressions gained by Dr Hauer from meetings with Caltrans professionals in the traffic engineering and highway design offices.

It appears that the relatively more centralized political system of the U.S. might be reflected in the prevailing state of affairs at Caltrans. Thus in FY 89/90 nearly 200 safety projects were undertaken under the headings: spot improvements, wet pavement correction, median barriers, guiderail, pedestrian fences, striping and marking, railroad grade separations and others. Of the $38 million spent, $30 million came from federal funding. Much of the activity at the state level (setting priorities, evaluation) revolves around making efficient use of these funds.

There does not seem to be at this time a long term research programme to support the activities of the state. Rather, State officials take the view that their needs are largely met by participation in AASHTO and that the research agenda is set between AASHTO and FHWA. State officials have an influence on what is done by both submitting research statements and by personal participation in various panels which take part in the formulation of research projects and in their monitoring. There is a modest size programme of funding research at universities. This programme appears to neither long-term nor in accordance with any plan.

Personnel who could be described as seasoned researchers in road safety appeared to be an

endangered species at Caltrans. This is especially surprising considering that in the 1960's and 1970's California contributed substantially to the available body of road safety knowledge. Although the old-time road safety experts might have retired, it does appear that the networking through AASHTO and the key role played by FHWA diminish the need for such State-based expertise and research.

4.2.7 Transport Canada

Although Transport Canada's mandate is vehicle safety, their past research efforts have reflected the difficulty of totally separate vehicle safety from roadway safety. For example, Transport Canada has funded research into safety evaluation methodology (**3.1**), on the safety of cross-section elements (**A2.6**), and on passing lane safety (**4.10**); and they have current research interests in such topics as roadway delineation. However, despite these interests, it is unclear whether future efforts would include a significant focus on roadway safety research. It is worth noting that in a discussion paper for a recent Transport Canada sponsored workshop (**4.11**) the list of emerging issues and the future directions recommended for Safety R&D did not contain any direct reference to roadway safety research.

4.2.8 Transportation Association of Canada (TAC)

TAC has recently identified key research needs in Transportation Safety as part of a National Research Agenda (**4.12**). The Agenda calls for the investigation of new methods, technologies and regulations to maximize the safety of transport systems and better ways to quantify those safety benefits for decision making and investment prioritization. The Agenda also calls for a study of the behavioural changes in the travelling population due to age, lifestyle, values, etc., and their impact on safety. A covering memorandum solicits research statements and states that those in priority areas identified in the Agenda will be given particular attention in TAC's current research programme. The identified safety issues include:

- The information needs of small communities and police forces.
- Lack of consistent accident data, and opportunities for better coordination and integration of data collection.
- Road safety as a public health issue, and the role of health care professionals as well as the transportation community.
- Uniformity and harmonization of traffic control practices.
- Highway investment planning with consideration given to highway safety issues.
- Consideration of pedestrians and bicyclists in highway strategies.
- The impact of new technologies on highway safety.
- An improved technical understanding of the impact of heavy vehicles on roadway traffic.

- The relationship between highway geometrics and road safety.
- Human factors related to motor vehicle accidents, including issues related to driver training and education.
- Behavioural changes in the travelling population due to age, lifestyle, values, etc.

4.3 Closure

At the beginning of this section three questions to be addressed in this section were posed:

(a) What is the structure of formal roadway safety research programmes in other jurisdictions?
(b) What elements of safety research have been identified as priorities elsewhere?
(c) What elements are currently being researched and will the MTO research programme, if carried out fully, duplicate research being done elsewhere?

In response to these questions we have attempted to extract the flavour of what of relevance is going on in other agencies.

With respect to the first question, it can be said in summary that roadway safety research in general is certainly topical and that the programme initiated by MTO, starting with this report, appears to be a worthwhile endeavour. Common themes among the agencies cited are a recognition of the needs for a structured approach to roadway safety research, for explicit consideration of safety in road design, for the development and retention of safety expertise, and for the rigorous evaluation of the safety consequences of design decisions. All of these are in concert with the programme recommended to MTO in this report.

With respect to the other two questions which deal with priorities, it appears that there is quite a diversity in priorities among the different agencies. Part of the reason is that the focus may vary among these agencies and there might even be a conscious attempt to avoid duplication in priority lists. Nevertheless, it can be said that the programme for safety research for specific elements that has been recommended to MTO is largely consistent with what the road safety profession as a whole sees as priorities.

On the issue of whether the programme recommended to MTO might duplicate efforts elsewhere, it should be pointed out that the fact that others are doing similar research or have it in their plans does not mean that they will do it or do it right, or that the findings will fulfil MTO's needs. Indeed, if what others are doing is relevant, MTO should not be wary of doing what might be perceived as repetitious research since, at

its most fundamental level, a research programme should thoroughly assess what has been done and, as important, what others are currently doing of relevance, and examine whether this is sufficient to review MTO policy and improve decision-making. As stressed in Chapter 3, for each of the research programmes recommended for roadway elements, the first task should be to assess whether it is necessary for MTO to proceed beyond the stage of reviewing and applying what others are doing.

REFERENCES (Section 4)

4.1 Transportation Research Board, "Designing Safer Roads: Practices for Resurfacing, Restoration, and Rehabilitation". Special Report 214, 1987.

4.2 Transportation Research Board, "Research Problem Statements: Design and Construction of Transportation Facilities". Circular 363, September 1990.

4.3 Transportation Research Board, "Safety Research for a Changing Highway Environment". TRB Special Report 229, 1990.

4.4 National Cooperative Highway Research Program (NCHRP), "Summary of Progress: December 31, 1990", Transportation Research Board, 1990.

4.5 American Society of Civil Engineers, "Engineering 21st Century Highways". Conference Proceedings, San Francisco, April 1988.

4.6 American Association of State Highway and Transportation Officials, "Keeping America Moving-Innovation: A Strategy for Research, Development and Technology Transfer". AASHTO, 1989.

4.7 U.S. Department of Transportation, Federal Highway Administration, "1990 FHWA Nationally Coordinated Program (NCP of Highway Research, Development and Technology". Report FHWA-RD-90-109, 1990.

4.8 American Society of Civil Engineers, "Engineering 21st Century Highways", Conference Proceedings, San Francisco, California, April 1988.

4.9 Institute of Transportation Engineers, "Safety Programs and Their Effect on Highway Standards". ITE

Informational Report, 1986.

4.10 ADI Limited, "Passing Manoeuvres and Passing Lanes: Design, Operational & Safety Evaluations". Report prepared for Transport Canada, March 1989.

4.11 ADI Limited and Davis Engineering, "Needs and Opportunities for Research and Development in Motor Vehicle Safety and Productivity in Canada". Workshop discussion paper prepared for Transport Canada, January 1990.

4.12 Transportation Association of Canada, "National Research Agenda 1992-1994", January 1992.

APPENDIX A SAFETY ASSESSMENTS

A1. INTERSECTION LIGHTING

The issues

Intersection lighting is relatively costly and might not always be effective in reducing target accidents. Thus, knowledge on the impact of intersection lighting on safety and on how this depends on a variety of factors is vital to decision-making on where installations might be cost-effective.

MTO policy

MTO directive B-6, 1978, states that partial illumination is to be considered for at-grade intersections where there is raised channelization or a traffic signal, or where 3 or more target accidents occur per year over 3 years, or where there is adjacent high-intensity illumination. In addition, illumination is to be considered for intersections on 4-lane undivided highways where warrants for traffic signals are fulfilled to at least 80%, and for intersections on multi-lane undivided highways where the through AADT exceeds 6,000.

Accident profile

According to tabulations in Appendix B, approximately 20% of all accidents on MTO roads (23% of fatal/injury accidents) occur at intersections. About 22% of these intersection accidents (37% of fatals) occur in darkness. Of the intersection accidents occurring during darkness, only about 15% are identified as occurring where ~~there~~ is artificial illumination. All of these statistics, taken together with the fact that only 15-20% of vehicular travel occurs during darkness, suggest that intersection lighting is an important safety issue.

A sample of previous research

A study on the effect of illumination on accident rates at rural Illinois intersections by Lipinski and Wortman (**A1.1**) compared accident data over a span of time equivalent to 445 intersection data years, with 263 lighted intersection data years and 182 unlighted intersection data years. Initially, seven measures of accident experience were actually considered, but the ratio of night accidents to total accidents was preferred since "the decision to install lighting was not randomized". It was found that the night accident rate (per million entering vehicles) was 45% less at lighted than at unlighted intersections. The ratio of night accidents to total accidents was 22% less at lighted intersection than at unlighted intersections. On this basis, it was concluded that illumination results in a 45% reduction in the night accident rate and a 22% reduction in the night accident/total accident ratio. **[Comment:** *The conclusions are rather sweeping since (a) the 45% does not control for differences other than lighting. That there was a decrease of 26% in the day accident rate, is surely a clue that the lighted intersections would have had fewer accidents to begin with. (b) The 22% change in the night/day ratio does not control for changes in the ratio of night/day traffic that may result from the installation of lighting.*]

Walker and Roberts **[A1.2]** examined the accident frequency for 3-year periods immediately before and after installation of lighting at 47 rural, stop-controlled, at-grade intersections where no major changes in geometric or traffic control were made at any time during the entire 6-year period. In general, traffic increased by approximately 11.6% from the before to the after period. It was also estimated that, for the 6-year period, 27% of the ADT at all the 47 intersections occurred during hours of darkness. The results revealed a 49% overall reduction in night accidents after lighting, a decrease from 90 before lighting to 46 after lighting. The average night accident rate per million entering vehicles was 1.89 before lighting and 0.91 after lighting, a reduction

of 52%. Channelized intersections and those with ADT's above 3,500 tended to have higher reductions in the night accident rate. Before lighting, the night rate exceeded the daytime rate by nearly 20%. After lighting, the night accident rate was some 34% less than the daytime rate. (All of the quoted reductions were deemed significant at the 99% level.) [**Comment:** *There are 2 main problems with the study. First the reduction in the night accident rate did not control for the reduction in the day accident rate, which fell by 12.7%. If this were done, the reduction in night accident rate would be only 45%. The other problem is that lighting was likely to have been installed where the recent night accident rate was high. (See California warrants below.) Thus the before and after comparison would overestimate the safety effect of lighting. Compare the 47% with the 22% obtained from the cross-section study above!*]

Reference **[A1.3]** cites some work in California **[A1.4]** as follows: 1967 data from the California Department of Public Works at intersections for which illumination was being considered indicated that 56% of all accidents were occurring after dark. The night accident rate was 2.88 per million entering vehicles. Lighting of these intersections reduced the average night accident rate to a much more satisfactory 1.08. These numbers were examined in the light of a warrant for installing lighting at intersections with more than 5 accidents per year and more than 50% occurring at night, or at those with less than 5 accidents per year of which 3 occurred at night. It was found that, at intersections where illumination was warranted, the average night accident rate was 4.59. This was reduced 72%, to 1.28 after illumination. When intersections were illuminated where lighting was not warranted, accident rates dropped from 1.49 to 0.92, a reduction of only 38%. [**Comment:** *It is unclear whether the California study is of the before and after or cross-section type, although the former is suspected. Obtaining the actual study report would help in appraising the results, but it seems likely that once again the safety effect of lighting would be overestimated. Also the difference between safety effect at warranted vs unwarranted intersections could be due to the fact that intersections were placed into the 2 groups on the basis of the accident count before lighting installation.*]

Finally, there appears to be relatively little work on the effect of quantity of illumination. An FHWA cross-section study 558 intersections in several urban areas concluded that "A decrease in the percentage of night accidents was not observed with an increased number of luminaires or reflectivity".

A final appraisal

The research studies referred to were all done in the 1970's or earlier so their relevance under today's conditions is open to question. The Iowa study is perhaps the best of the lot but yet that study suffered from two potentially fatal flaws. The overall % reduction of about 50% agrees with the California study but, for reasons explained, this figure is likely an overestimate. In the cross-section study (Lipinski et al.), when the daytime accident rate is used as a control, the difference in accident rate between the lighted and unlighted intersections is about 20%. This probably constitutes a lower bound on safety effect of intersection lighting.

Assessment of MTO policy

For reasons explained in many parts of this report, it is undesirable to have a warrant based on the count of accidents over a short time period. (It has been shown that 3 years is still too short a time to overcome the vagaries of random fluctuation.) This aspect of the directive needs to be reviewed. There appears to be some support for the notion in the MTO directive that lighting is more effective for channelized intersections and those with high AADT. Since lighting also appears to be effective under other conditions, it is open to question whether the MTO directive as to which intersections are to be considered is as clear-cut as indicated. In summary, it seems desirable to replace most elements of the directive with a simple requirement that a cost-

benefit analysis be conducted on the basis of the expected change in the number and severity of target accidents. The knowledge to implement this requirement needs to be acquired.

Research need

Even if the estimates from the literature are accepted as valid, important questions remain and need to be answered for Ontario roads: Is lighting installation at intersections more effective under some conditions than others? If so, how can such information be used in examining the cost-effectiveness of lighting an intersection? Before attempting to examine these questions for Ontario roads, basic information such as the frequency of accidents at unlighted intersections is needed. This would identify a potential group of target accidents for the research, and in the first place whether further research can be cost-effective.

References

A1.1 M.E. Lipinski and R.H. Wortman, "Effect of Illumination on Rural At-grade Intersection Accidents" Transportation Research Record 611. Transportation Research Board,Washington, D.C., 1976.

A1.2 F. W. Walker and S.E.Roberts, "Influence of Lighting on Accident Frequency at Intersections," Transportation Research Record 562, Transportation Research Board, Washington D. C., 1976.

A1.3 "Synthesis of Safety Research Related to Traffic Control and Roadway Elements", FHWA report FHWA-TS-82-232, December 1982.

A1.4 "Evaluàtion of Minor improvements: Flashing Beacons, Safety Lighting, Left Turn Channelization", Traffic Department, California Department of Public Works, 1967.

A1.5 "Motor Vehicle Accidents in Relation to Geometric and Traffic Features of Highway Intersections", U.S. Department of Transportation, Federal Highway Administration Report No. FHWA-RD-76-129, 1976.

A2. SHOULDERS (includes lane width)

The issues

Major functions of a shoulder are to provide lateral support to the traffic lanes, to provide a recovery area for errant vehicles, to provide refuge for disabled vehicles, to increase lateral clearance, and to allow moving vehicles to pass vehicles stopped in the traffic lanes. Given this variety, it is not always clear which of these should provide the basis for shoulder width, type and treatment standards. Nevertheless, since all of these functions can be linked to safety, and, according to the MTO Geometric Design Manual, "shoulders provide an area that may be used to avoid a potential accident or to minimize the severity of an accident", knowledge on the relationship between accident occurrence and shoulder width and type and on how this depends on lane width is vital to the design of shoulders, the selection of lane width, and to decision-making on upgrading existing shoulders.

MTO policy

Standards for shoulder width and type and for lane width are given in the MTO Geometric Design Manual, Section D.5 and D.2 respectively. For undivided rural roads, and for right shoulders of 4-lane divided highways, widths vary from 1.0 m to 3.0 m depending on design speed and AADT. For multi-lane divided highways, the right shoulder width is 3.0 m. Left shoulder widths are generally 2.5 m for multi-lane divided highways and 1-1.5 m for 4-lane divided highways. The Manual indicates that shoulders are gravel surfaced unless full or partial paving is warranted by AADT and highway classification. Full paving is warranted for multi-lane freeways and, under specified conditions, for urban roadways. Lane widths vary from 2.75 to 3.75 m depending on factors such as road classification, number of lanes, design hourly volume, and design speed.

Accident profile

It is usual to consider run-off-road accidents, including those where fixed roadside objects are struck, and opposite direction accidents as the accident types potentially affected by shoulder width and type and lane width. 1988 MTO data in Appendix B indicates that, on MTO roads, single vehicle accidents account for about 49% of all accidents (57% of fatals) while "approaching" accidents represent about 3% of all accidents (24% of fatals). Run-off-road accidents, including those where fixed roadside objects are struck, constitute about 21% of all accidents (29% of fatals). Taken together, these statistics indicate that the target accidents for shoulder safety research are considerable in number, particularly in the case of fatal accidents.

Accident profiles for Ontario roads, shown in Appendix B, give an indication of accident rates on MTO roads with various shoulder widths. For example, 2-lane rural roads with narrow shoulders and those with paved shoulders tend to have higher single vehicle accident rates.

While shoulders might mitigate these accidents, they are also associated with accidents involving vehicles which park on them. In Ontario, a study by Hauer et al. (**A2.1**) found that these accidents constitute about 4 to 4.5% of all accidents occurring on freeway sections coming under recent legislation to prohibit parking. More recently, Agent et al. (**A2.2**) found that vehicles on freeway shoulders in Kentucky accounted for 1.8% of all accidents but 11.1% of fatal accidents.

A sample of previous research

Zegeer et al. (1985) (**A2.3**) conducted an extensive review of earlier research prior to conducting some new research. They concluded that the prior research supports their own results indicating that accident rate decreases with increasing lane and shoulder width and with the quality of the shoulder surface but that, in terms of accident eliminated per foot of added width, widening lanes has a bigger pay off than widening shoulders. Also, the marginal effects of shoulder width increments are diminished as either the base lane or shoulder width increases. There appears to be some support for these inferences in some recent results from a before-after study by Benekohal et al. (**A2.4**) who found that on two-lane RRR projects in Illinois, there was a reduction in accidents after shoulder widths were reduced to accommodate increase lane widths. This finding was however compounded by the fact that other improvements were carried out at the same time.

Zegeer et al.'s own study (**A2.5**) examined accident experience on 4951 miles of 2-lane roads in the U.S. and found that run-off-road (ROR) and opposite direction (OD) accidents were reduced as shoulder width was increased. A sample of the results show reductions of 16%, 29% and 40% for paved shoulder widening of 2, 4 and 6 ft., respectively. These percentages are slightly less for unpaved shoulders and vary with lane width; for example, adding a 2 ft. shoulder to a highway with 11 ft. lanes will eliminate fewer accidents than adding 2 ft. shoulders to a highway with 9 ft. lanes. It is suggested that the widening of lanes and shoulder will be more effective on roads with sharp curves and dangerous roadsides. [**Comment**: *Zegeer et al., like many of the other cross-section type studies they review, incorrectly make inferences that differences in accident experience between different roads are due to differences in a particular feature (shoulder width in this case) when in fact many other things could be different. The regression models on which they base these inferences only control for differences in ADT, terrain and roadside hazard.*]

Dean (**A2.6**) analyzed carefully chosen 2-lane road sections in New Brunswick in which shoulder width was the only apparent geometric variable. Sections with wider shoulders had fewer accidents in each ADT group with the relationship being more pronounced for narrow shoulders and apparently confirming RTAC's recommendation of a 6 ft (2 m) optimum shoulder width. [**Comment:** *Unlike Zegeer, the authors did not infer accident reduction factors from the cross-section study, recognizing that despite their best efforts, they could not control for all relevant factors.*]

Before-and-after type studies, if properly done, tend to give "truer" results than cross-section studies. Aside from Benekohal et al.'s study, the three of note in the literature are by Rinde (**A2.7**) (1977) in California and Rogness (**A2.8**) (1982) in Texas and Goldstine (**A2.9**) (1991) in New Mexico. Rinde looked at projects on 143 miles (230 km) of road that included combinations of pavement and shoulder widening of existing 2-lane alignment to include two 12 ft. lanes. Rogness et al. examined 2 years each of data before and after adding full-width paved shoulders to 30 two-lane road sections covering 214 miles. Goldstine looked at 25 two-lane RRR projects covering 152 miles and found that accident reductions depended on the AADT and the amount of widening. In the 3 studies, the accident rate reductions tended to be higher than those inferred by Zegeer. [**Comment:** *(1) Although the accident rate reductions were attributed entirely to the widening, some of the reduction may be due to other factors. For example, for the Rinde and Goldstine studies, improved signing, striping, intersection geometrics, some small curve corrections and the new surfacing constructed concurrently with the widening may have had some influence. (2) The extent to which a randomly high accident count in the before period might have influenced the selection of shoulder widening locations is unknown. If such a count were used in the before and after analysis, it is possible that the reduction in accidents were overestimated.*]

The final study reviewed on safety implications of shoulder width (**A2.10**) concluded that wide paved shoulders (6 - 10 ft) are cost-beneficial on Texas highways for AADT levels above 1,500 vehicles/day. The safety benefits were inferred from a cross-section study of relevant accidents so this study might suffer from the same limitation as Zegeer's.

While there is considerable literature of shoulder width and safety, there is relatively little on shoulder type aside from the Texas study (**A2.10**). We have found excerpts from an MTO report from the late 1970's which examined the safety benefits of partial shoulder paving. From what we could decipher, 2 ft partial shoulder paving was most beneficial on 2-lane highways for which the reduction in shoulder related accidents was of the order of 6% to 16%. It is not clear whether the analysis was of the before-and-after or cross-section type. One item of note in the literature is a suggestion by Cirillo and Council (**A2.11**) that "when shoulders exist, particularly on high volume roads, they should be paved". The basis of their suggestion is a study by Fee et al. (**A2.12**) of the U.S. Interstate system from which they conclude that "other than access control, no geometric element has shown a more consistent relationship to safety (i.e., reduced accidents) than shoulder type". In support they quote Fee et al.'s results that accident reduction due to paved shoulders range from 1.3 accidents/year per 10,000 AADT for mainline freeway sections to 4 accidents/year for loop ramps. [**Comment:** *As we commented elsewhere, cross-section study results can be subject to question. Also, the study was for freeways, so the applicability of the results might not be as broad as Cirillo and Council's statements indicate.*]

A final appraisal

Cross-section type studies, such as Zegeer's tend to affect results in 2 ways. One could overestimate the effect of the feature of interest because other factors could be responsible for safety differences. Or, one could underestimate the effect since shoulders might have been installed where accident occurrence was high to begin with. Zegeer's numbers appear to have more of the latter than the former since they appear to be smaller than the those for the before-and-after studies. Since the latter numbers might, for reasons mentioned above, be overestimates, it appears that Zegeer's numbers might be constitute a reasonable lower bound.

Assessment of Ontario policy

The available literature, if assumed valid, would suggest that MTO shoulder width standards are adequate, but that they should perhaps be tied to lane width, given that there can be some variability in lane width for a given AADT and design speed. For roads with a lower shoulder standard, consideration should be given to developing a warrant for identifying sections (e.g., curves) where a higher standard shoulder might be appropriate. On the basis of findings in the literature reviewed, the cost-effectiveness of shoulder widths greater than 2 m on 2-lane roads is open to question. However, on the basis of preliminary indications in MTO accident data, it might be reasonable to question the validity of those findings. The MTO guidelines for shoulder surfacing could not be evaluated on the basis of the literature reviewed. These guidelines should be evaluated in the light of suggestions in the recent paper by Cirillo and Council (**A2.11**) and the indications given by Ontario accident profiles in Appendix B.

Research need

The MTO experience with shoulder widening should be evaluated, desirably in a before and after study that examines the interaction with lane width, among other factors. Such a study would also utilize regression models such as Zegeer at al's. However, in view of Ng et al.'s indication (**2.12**) that there should be different models for the different States combined in Zegeer et al's data, it is desirable that regression models be constructed for Ontario data. Such an effort would come under basic research to construct multivariate models of accident potential for Ontario road sections.

References

A2.1 Hauer E., Lovell J. and B. Persaud, "Safety measures aimed at reducing accidents occasioned by vehicles stopped on freeway shoulders". University of Toronto, 1985.

A2.2 Agent K. and R. Pigman, "Accidents Involving Vehicles Parked on Shoulders of Limited Access Highways". Transportation Research Record 1270, 1990.

A2.3 Zegeer C.V. and J.A. Deacon, "Effect of lane width, shoulder width and shoulder type on highway safety: A synthesis of prior literature". Prepared for Transportation Research Board, 1985.

A2.4 Benekohal R. and M. Lee, "Comparison of Safety Effects of Roadside vs Road Improvements on Two-Lane Rural Highways". Preprint, Paper No. 910509, Transportation Research Board Annual Meeting, January 1991.

A2.5 Zegeer C.V., Reinfurt D.W., Hummer J., Herf L. and W. Hunter, "Safety effects of cross-section design for two-lane roads". Transportation Research Record 1195, 1988.

A2.6 Dean J., "Shoulder design standards and highway traffic safety, Phase II". University of New Brunswick Report prepared for Transport Canada, July 1976.

A2.7 Rinde E.A., "Accident rates vs. shoulder width". FHWA and California DOT report CA-DOT-TR-3147-1-77-01, 1977.

A2.8 Rogness R.O., Fambro D.B. and D.S. Turner, "Before-after accident analysis for two shoulder upgrading alternatives". Transportation Research Record 855, 1982.

A2.9 Goldstine R., "Influence of Road Width on Accident Rates by Traffic Volume". Preprint, Paper No. 910030, Transportation Research Board Annual Meeting, January 1991.

A2.10 Woods D., Rollins J. and L. Crane, "Guidelines for using wide-paved shoulders on low-volume two-lane rural highways based on benefit/cost analysis". Texas Transportation Institute Report FHWA/TX-89/1114-1F, 1989.

A2.11 Cirillo J. and F. Council, "Highway safety: Twenty years later". Transportation Research Record 1068, 1986.

A2.12 Fee J., Bietz S., and R. Beatty, "Analysis and modelling of the relationships between accidents and the geometric and traffic characteristics of the interstate system". FHWA, 1969.

A2.13 Ng J.C. and E. Hauer, "Accidents on rural two-lane roads: Differences between seven states". Transportation Research Record, 1989.

A3. ACCESS CONTROL

The issues

The main issue in access control from MTO's perspective is the relationship between accident occurrence and the frequency of access points on roads without full access control. Such knowledge would enable the review of current access spacing policies and, if necessary, the development of policies that explicitly consider the safety of access points.

MTO policy

The MTO's policy is to allow 14 private access points and 5 public access points for a total of 19 access points per kilometre. The MTO policy objective as discussed by Horton et al. (**A3.1**) is that accident rates on all provincial highways should not exceed the current provincial average accident rate of 1.1 accidents/MVKM.

Accident profile

Accident tabulations in Appendix B indicate that 6.5% of all accidents on MTO roads occur at or near private drives, while about 21% (11% of fatal) are intersection related.

A sample of previous research

A study by Horton and Sillaste (**A3.1**) for MTO examined the relationship between accident rate and access spacing as part of a review of the MTO access policies. The study attempted to relate total accidents on 204 km of highway sections to the frequency of private access points. The sections were divided into two and four-lane, and high and low speed facilities. The authors infer that accidents increase with frequency of driveway access. [**Comment:** *Because of the considerable scatter in the data, the calibrated relationships between safety and access spacing does not appear to be on strong foundation. Moreover, it is not likely that the authors were able to control for all of the factors that account for differences in accident rates between 2 sections. Finally, the use of total accidents could give misleading results.*]

A study by Schoppert (**A3.2**) attempted to develop equations which could be used to predict accidents on two lane highways from various roadway elements including frequency of access points. The study used 3 years of accident data from a sample of 1374 miles of two lane rural highway with gravel shoulders in Oregon. It was found that the most important predictor of accidents is traffic volume followed by points of access and then design features such as lane and shoulder width. On low volume roads (<2,000 ADT), however, accident rates did not appear to have a strong relationship with any roadway feature, a finding confirmed by Head (**A3.3**) for urban extensions of state highways in Oregon.

Cirillo et al. (**A3.4**) in a study reported in (**A3.5**) found accident rates of 1.26 accidents per million vehicle miles for 2-lane rural roads with 0.2 intersections and 1 business entrance per mile compared with 2.70 and 17.18 accidents per million vehicle miles for roads with, respectively, 2 and 20 intersections per mile and 10 and 100 business entrances per mile.

Stover et al. (**A3.6**) used simulation to suggest that access point spacing should be greater than 1.5 times the distance needed for entering vehicles to accelerate to the speed of the traffic stream. This translates into a spacing of 1100 ft (5 access points/mile) for an acceleration rate of 3 fps/s and a stream speed of 45 mph.

A final appraisal

Attempting to infer the influence of driveway frequency on accident occurrence from regression analysis is difficult because of the variety of factors that influence accident occurrence. The one Ontario study is recent but was an extremely limited effort. The result is that the conclusions are not strong since all the factors affecting accident occurrence could not be properly accounted for. Other studies are more substantive but tend to be old and based on U.S. data.

Assessment of MTO policy

On the basis of the literature reviewed and of the MTO study it is not possible to assess the validity of current MTO policy on access spacing. It is clear that the policy is a broad one and that an effective policy should specify maximum access frequency as a function of AADT, road class, design speed. The knowledge on which to base such a policy does not currently exist.

Research need

To establish the relationship between access spacing and accidents in Ontario requires a careful study with extensive data requirements. A major requirement would be to obtain data for carefully matched sections in which access spacing is the only difference. The feasibility of obtaining such data must be examined before a recommendation can be made on whether research might be fruitful. As a start, it might be useful for the MTO to conduct a review of current policies and driveway accident frequency in various North American jurisdictions, and to examine MTO policy and accident occurrence in this light.

References

A3.1 Horton J. and L. Sillaste, "Relationship of Private Entrances to Highway Efficiency". Research and Development Branch, Ontario Ministry of Transportation, November 1988.

A3.2 Schoppert D.W., "Predicting Traffic Accidents From Roadway Elements of Rural Two-Lane Highways with Gravel Shoulders", Highway Research Board Bulletin 158, 1957.

A3.3 Head J., "Predicting Traffic Accidents From Roadway Elements on Urban Extensions of State Highways", Highway Research Board Bulletin 208, 1959.

A3.4 Cirillo J. et al., "Interstate system accident research study-1, Volume 1 - Comparison of accident experience on interstate and non-interstate highways". Report of the Bureau of Public Roads, October 1970.

A3.5 Federal Highway Administration and Texas A&M University, "Synthesis of safety research related to traffic control and roadway elements". FHWA report FHWA-TS-82-232, 1982.

A3.6 Stover V., Adkins G. and J. Goodnight, "Guidelines for median and marginal access control on major highways". NCHRP report 93, TRB, 1970.

A4. CLIMBING LANES

The issues

A drop in speed upgrade caused by slow moving vehicles, as compared with the prevailing speed, could present a safety hazard because of unsafe manoeuvres that are made while other vehicles try to pass slow moving vehicles. It is believed that the higher the speed differential between the upgrade average speed and the approach speed, the higher is the risk of accidents. While climbing lanes could mitigate this problem, they could also create hazards at the start and end. Knowledge on potential safety impact of climbing lanes is useful in assessing the overall cost effectiveness of potential installations so that these can be prioritized.

MTO policy

The MTO Geometric Design Manual, Section D2.3, makes provision for climbing lane installation on upgrades when the speed of the design truck (200 kg/kw) is 15 km/h below the 85th percentile speed of traffic and the level of service drops by one or more levels. Curves are provided for predicting truck speed for various upgrades and lengths of grade. More recently, Khan (**A4.1**) has developed a procedure for explicitly trading-off the costs and benefits of any potential installation. Presumably this procedure, which resulted from research conducted for MTO, will replace the need for the discrete warrants.

Accident profile

Accident tabulations in Appendix B indicate that approaching accidents, which include several accidents which might be directly or indirectly affected by climbing lanes, account for only about 3% of all accidents on MTO roads, but about 24% of fatal accidents. Included in the group of approaching accidents are "improper passing" accidents which account for about 2% of all accidents. The number of approaching and rear-end, non-intersection accidents occurring on hills on 2-lane roads might serve as an upper bound on target accidents that might be directly affected by climbing lanes. The tabulations in Appendix B indicate that only 89 accidents in 1988 were coded in this category. [It is possible that this suspiciously low number might have resulted from coding problems.]

A sample of previous research

There are relatively few studies that deal with the safety of climbing lanes.

Jorgenson (**A4.2**) reviewed a small number of climbing lanes in the U.S. and found no change in accident experience with the use of climbing lanes, while Voorhees (**A4.3**) found a 13% reduction due to the provision of climbing lanes.

ADI (**A4.4**) mention a study in Sweden (**A4.5**) that shows accident rates (per million axle pair km) of 0.44 and 0.64 respectively for hills with and without climbing lanes. ADI indicated that these figures suggest reductions in accident rates of 31% for hills with climbing lanes. This value contrasts sharply with results of a before-and-after study which showed that the 26% reduction in accident rates at 12 sites where climbing lanes were installed was not significantly greater than the decrease experienced on untreated control sections. [**Comment:** *This is another example of the dangers of making inferences from cross section studies. In the case of the before-and-after study, however, it is possible that the decrease at the untreated control sites might be due to a spillover effect from the treated sites. The Swedish study, which was not available to us at the time of writing, requires more*

careful examination.]

In Khan's study (**A4.1**), the reduction of delay and reduction of accident involvement rate/100 million vehicle km are used in a microcomputer program to estimate the cost-effectiveness of potential climbing lane installations. The reduction in speed differential (from some level to zero) is used to estimate safety effectiveness (the difference in truck accident rates for the 2 speed differential levels) using a curve presented by AASHTO (**A4.6**) and taken from Glennon (**A4.7**). Glennon's curve relating truck involvement rate to speed differential on upgrades is inferred from Solomon's famous U-shaped curves (**A4.8**) linking accident involvement rate to travel speed. [**Comment**: *There are two fundamental assumptions in Khan's use of the AASHTO curve, both of which may not be strongly founded. First, that only truck accidents are affected by the introduction of climbing lanes might be questionable. Second, it is unclear whether Solomon's U-shaped curve (1964) is valid for Ontario in the 1990's. Further, the differences in involvement rate found by Solomon might be due to factors other than speed differential. Thus elimination of the speed differential does not guarantee reductions in involvement rates implied by Solomon's curve.*]

Khan et al. cite other studies on safety of climbing lanes, including those mentioned above, but conclude that the state of knowledge on the safety effectiveness did not permit its treatment to the same degree of detail as for level of service.

A recent paper by St. John et al. (**A4.9**) has since addressed some of the issues raised in Khan's study. The paper showed how speed profiles of trucks on upgrades can be used along with safety estimates to quantify the increased accident rates of slow moving trucks and the changes in accident rate with distance up the grade. Although truck performance and speed data were based on recent work, the effect of speed differences on accidents was based on Solomon's relationships. Their results indicate that there is little safety justification for truck climbing lanes at locations where essentially all truck speeds remain above 22.5 mph (37.5 km/h). The authors recommend further research in the light of apparent flaws they found in Solomon's data, specifically, in the 0-22.5 mph speed range.

A final appraisal

While we concur with Khan's appraisal of the state of knowledge, we believe that the recent work by St. John and Harwood at Midwest Research Institute (MRI) requires careful examination to see how applicable it is to Ontario and what gaps remain to be resolved.

Assessment of MTO policy

It is difficult to assess a policy that is apparently in transition. However, there seems to be a clear need for MTO to review the safety aspects of both the current warrants and the new procedure especially in the light of the recent and on-going MRI work. If the results of that work are found valid for Ontario then it would appear that fewer climbing lanes should be warranted than are under the current warrants.

Research needs

A research project is needed to (a) verify the relationships used by Khan (and Glennon and Solomon), and (b) if necessary, to evaluate the safety effectiveness of climbing lanes installed by MTO. Naturally, a major aspect of such a project would be to assess the applicability of relevant work being done elsewhere. There also seems to be a need to first get a better feel for target accidents than could be obtained from a cursory examination of coded accident data. This would indicate the level of research effort that might be worthwhile.

References

A4.1 Khan A. and N.M. Holtz "Cost Effectiveness of Climbing Lanes", Research and Development Branch, Ministry of Transportation, Ontario, March 1990.

A4.2 Jorgensen R., "Evaluation of Criteria for Safety Improvements on the Highway", U.S. Dept. of Commerce, Bureau of Public Roads, 1966.

A4.3 Voorhees A., "Crawling Lane Study: An Economic Evaluation", Department of Environment, Great Britain, 1968.

A4.4 ADI, "Evaluation of Passing Lane Safety", Prepared for Transport Canada, September 1988.

A4.5 Swedish National Road Administration, "Road Safety of Climbing Lanes", Analysis of Accidents from 1972-1977.

A4.6 American Association of State Highway and Transportation Officials, "A Policy on Geometric Design of Highways and Streets", Washington D.C., 1990.

A4.7 Glennon J.C., "An Evaluation of Design Criteria for Operating Trucks Safely on Grades", Highway Research Record 312, 1970.

A4.8 Solomon D., "Accidents on main rural highways related to speed, driver and vehicle", U.S. Department of Commerce, July 1964.

A4.9 St. John A. and D. Harwood, "Safety Considerations for Truck Climbing Lanes". Transportation Research Record 1303, 1991.

A5. PASSING LANES

The issues

Long stretches of 2-lane roads with slow moving vehicles and relatively few passing opportunities reduce efficiency and could be unsafe if driver frustration causes erratic passing manoeuvres. It is believed that the installation of passing lanes at 5-10 km intervals could mitigate these problems. The main issue is how frequent (if at all) passing lanes should be installed on a section of road. This depends on how many accidents might be saved. Secondary issues are under what circumstances should opposing traffic be allowed to use the passing lanes and whether potential safety problems at the ends of a passing lane are sufficient to offset the overall benefits.

MTO policy

The only guideline on passing lanes that we have been able to find is in Section D2.3 of the MTO Geometric Design Manual which states that passing lanes are similar to truck climbing lanes but are not necessarily located on upgrades. According to this manual, passing lanes are applied to 2-lane roads carrying large volumes of slow-moving vehicles, e.g., recreational routes. More recently, Khan (**A5.1**) is developing a procedure for explicitly trading-off the costs and benefits of any potential installation. Presumably this procedure, which is resulting from research conducted for MTO, will replace the need for warrants.

Accident profile

A broad feel for target accidents can be extracted from the tabulations in Appendix B which indicate that approaching (head-on) non-intersection accidents on 2-lane roads accidents account for only about 2% of all accidents on MTO roads. These accidents, however, constitute about 17.5% of all fatal accidents. For most of the approaching accidents the apparent driver action is given as improper passing.

A sample of previous research

Khan's study (**A5.1**) is developing a microcomputer program to estimate the safety and traffic flow benefits and to use these estimates in analyzing the cost-effectiveness of potential passing lane installations, similar to the procedure for climbing lanes. The average speed improvement, ranging from 0 to 15 km/h is used to estimate safety effectiveness (the difference in accident rates) using the same relationship as that used for climbing lanes. Again, it should be emphasized that these relationships were originally derived for truck involvement rates. [**Comment**: *As indicated in Section A4, the fundamental assumptions in use of this relationship may not be strongly founded. In the case of passing lanes it is especially questionable that only truck accidents are affected by their introduction and that, as Khan points out, the safety benefits are obtained only where the lane is installed. Again it should be pointed out that obtaining better information on safety benefits appeared to be outside of Khan's mandate. Indeed, Khan emphasizes that "a better insight into the subject of safety and improved accident data base could be gainfully used to update the methodology".*]

There is relatively little other relevant work on the safety of passing lanes.

Rinde (**A5.2**) refers to a before-and-after study of 19 road widening projects in California that found accident rate reductions of 25% to 27% with the provision of passing lanes.

Harwood et al. (**A5.3**) evaluated the safety effectiveness of passing lanes using 1 to 5 years of accident data at 13 passing lane sites and 13 matched 2-lane sections. The passing lanes had 38% fewer total accidents and 29% fewer severe accidents (per million vehicle miles). These values contrast sharply with results from Harwood et al.'s before-and-after study (**A5.4**) of 22 passing lane installations which showed reductions of 9% for all accidents and 22% for severe accidents. These comparatively low effectiveness values were subsequently combined with Rinde's results by Harwood (**A5.5**) to suggest that passing lanes will, under average conditions, reduce accidents by 25%.

More recently, Taylor and Jain (**A5.6**), estimated passing lane accident benefits by comparing accident rates on 2-lane rural roads with and without passing lanes in Michigan. Results are given by accident type for three ADT ranges. For example, the benefit for injury accidents ranges from 14.7 accidents per million vehicle miles (a 20% reduction) for ADT's of 5000 to 10000 to 43.1 accidents per million vehicle miles (a 42% reduction).

The safety of using one passing lane by both opposing lanes of traffic has been addressed in a few studies. Harwood et al. concluded that the provision of passing by vehicles in the opposing direction to the passing lane did not appear to lead to any safety problems at their study sites. However, the study referred to by Rinde (**A5.2**) found significant accident reductions at one site where opposing vehicles were prohibited from using a passing lane that they were previously allowed to use. Though Rinde questioned the reliability of results from 1 site that might have had a high accident rate before, he recommended that opposing traffic not be allowed to use the passing lane if traffic volume exceeds 3000 vehicles per day.

With regard to potential safety problems at the ends of the passing lanes Harwood et al. reported that there were no unusual safety problems at these locations.

A final appraisal

The studies cited indicate that passing lanes could reduce the severe accident rate <u>where installed</u> by at least 20%. (Numbers from Rinde's study and the 2 cross-section studies (**A5.2, A5.6**) could be high, as is indicated by Harwood et al.'s before-and-after study - Rinde's because passing lanes might have been installed where there was a randomly high accident count, and the cross-section studies because sections with passing lanes might be inherently safer in other features.) However, one might expect that accidents would also be reduced in the surrounding 2-lane sections since passing lanes would reduce unsafe manoeuvres there. There appears to be no knowledge on this issue.

Assessment of MTO policy

If, indeed there are no MTO guidelines on where passing lanes might be warranted, these should be developed. As a guide, warrants used by other jurisdictions might be examined (e.g. Saskatchewan; see 1990 CITE conference proceedings). It should be noted that the AASHTO 1990 Policy on Geometric Design prefers climbing lanes over passing lanes because of a concern for drivers entering a passing lane and thinking that they are entering a 4-lane road.

Research needs

Research using Ontario data before and after passing lane installation could yield valuable insights, providing the study area includes the entire road sections that might be influenced by the passing lane installation. Comments in Khan's study for MTO would appear to support this statement.

References

A5.1 Khan A., N. Holtz and Z. Yicheng, "Cost-Effectiveness of Passing Lanes: Safety, Level of Service and Cost Factors". Report prepared for the Research and Development Branch, Ministry of Transportation, Ontario, March 1991.

A5.2 Rinde E., "Accident Rates vs Shoulder Width", California Department of Transportation, Sacramento, California, 1977)

A5.3 Harwood D.W., A. St. John, and D.L. Warren, "Operational and Safety Effectiveness of Passing Lanes on Two Lane Highways". Transportation Research Record 1026, TRB 1985.

A5.4 Harwood D.W. and A. St. John, "Passing Lanes and Other Operational Improvements on Two-Lane Highways". Federal Highway Administration Report FHWA/RD-85/028, 1985.

A5.5 Harwood D.W., "Operational and Safety Experience with Passing Lanes". Compendium of Technical Papers, Institute of Transportation Engineers 58th Annual Meeting, 1988.

A5.6 Taylor W.C. and M. Jain, "Warrants for Passing Lanes". Transportation Research Record 1303, 1991.

A6. UTILITY AND SIGN POLES

The issues

The frequency and severity of collisions with poles and posts on the roadside are related to pole type, offset and spacing. Knowledge on the relationship is useful for the design of these features, as well as for decision-making on how to reduce the frequency and severity of these collisions.

MTO policy

The MTO Traffic Barrier Manual notes that sign posts with fragile bases and light poles do not constitute obstacles and do not warrant barrier protection since the barrier creates a larger area of exposure than the existing feature. Presumably then, light poles and sign posts should be located in accordance with unprotected clearance distances given in hazard protection distance warrants (Figure 3.2 of the Manual). These distances vary with design speed from 10 m at 120 km/h to 3 m at 60 km/h for new highways. The absolute minimum clearances for existing highways are one-half of the values for new highways.

Accident profile

Accident tabulations in Appendix B indicate that in 1.1% of all accidents on MTO roads the first object struck is a pole or post. 73% of these accidents are classified as property damage only. By contrast, if all Ontario accidents are considered, about 4% of accidents involve vehicles striking poles and posts. In the U.S. as a whole, 1988 data (**A6.1**) indicate that utility poles and posts account for almost 20% of fixed object collisions. Comparable figures for Ontario are 23% for all roads and 12% for MTO roads only.

A sample of previous research

A literature review of the accident effects of roadside features conducted by Solomon (**A6.2**) includes studies which provided information on the incidence and severity of accidents involving sign poles as well as light poles. One such study (**A6.3**) was based on a sample of 1637 accidents and determined the proportion of all accidents involving sign poles and lighting poles as a function of the lateral distance of the pole from the edge of the highway pavement. Fixed poles produced more severe accidents with more than three times as many fatal accidents for each 100 accidents, based on a sample of only one break-away fatal accident and 19 fixed pole fatal accidents. [**Comment:** *In Ontario, combination of the 1985, 1986 and 1987 figures for all Ontario roads show that fixed poles have 1.5 times as many fatal accidents per 100 accidents.*]

A study conducted by Zegeer et al. (**A6.4**) was intended to determine the effects of various traffic and roadway variables on the frequency and severity of utility pole accidents. This study used detailed roadway data and accident data for 9583 utility pole accidents covering 2 to 10 years for 1534 sections of roadway in Michigan, Colorado, Washington, and North Carolina. A regression model was developed to predict utility pole accident occurrence as a function of pole density, ADT and average pole offset for a road section. Pole offset was found to be the single factor that explains the largest amount of variance. The highest utility pole accident frequency was found on highway sections with pole density of 45 poles/km or more, ADT greater than 15,000 and average pole offset of 6 ft (1.8 m). The roadway variables that have a significant relationship with severity of accidents (percentage of injury plus fatal accidents) are horizontal curvature, speed limit, and pole type. [**Comment:** *Caution should be used in using the regression model to predict the effect of altering one variable, e.g., increasing*

pole offset. This is because the regression model might not contain all variables that explain utility pole accident frequency. It could be argued, for example, that a lower frequency on roads with larger offset might be due to the fact that such roads have better geometrics in general.]

A similar caution is necessary in interpreting some more recent work by Zegeer and others (**A6.5**). Using a dataset of 1080 roadway sections in 7 States, regression models were calibrated to relate accidents to various fixed objects to a number of relevant variables -- ADT, fixed object frequency, lane width, distance of the object from the roadway, and type of terrain. The models for utility poles had the best fit and indicated for example that relocating poles 1 m further from the road would reduce utility pole accidents by 35%. The authors of this study recommend however that Zegeer et al.'s earlier models (**A6.4**) should be used, especially since an associated computer programme is available for computing accident benefits and project costs for a wide range of roadway conditions.

The injury reduction capabilities of breakaway light standards was addressed in a study for NHTSA (**A6.6**) by Kurucz. Based on an analysis of accidents at 16 breakaway standards and 35 rigid (mainly concrete and steel) standards, regression models were calibrated to relate the probability of an accident being severe to impact velocity, pole type and seat belt usage. The models indicate, for example, that approximately one-sixth as many drivers would receive serious injuries from striking light poles on high speed highways if breakaway standards are used instead of rigid ones.

On the issue of whether barrier protection might be useful for rigid standards, the same NHTSA study examined accidents to rigid objects (mostly utility posts, light standards and trees) and to protective barriers (mostly W-beam guardrail with concrete posts). Models were calibrated to relate the probability of an accident in each case being serious to impact velocity, seat belt usage and occupant seating position. The models indicated, for example, that the probability of serious injury from striking a guardrail at high speed (90 km/h) is approximately one-eighth of the probability for striking a rigid object. The paper notes the obvious caution that total impacts might increase due to the increased width of target presented by the guardrail.

A final appraisal

Offset and spacing: The most useful piece of knowledge seems to by provided by Zegeer's work. For reasons mentioned above, however, the model would give an upper bound on accidents reduced by increasing pole offset or spacing.

Pole type: It is clear that breakaway poles mitigate severity. The NHTSA sponsored study (**A6.6**) provides some guidance on quantifying these benefits.

Pole protection: The NHTSA models (**A6.6**) provides useful guidance on when it might be beneficial to protect rigid poles

Assessment of MTO policy

Assuming that Zegeer et al.'s figures are valid, then it would appear that MTO's guidelines for locating unprotected poles and posts are adequate. For reasons mentioned above this policy should be reviewed in the light of Ontario data as well as the results of the NHTSA sponsored study. For rigid poles in the clear zone, the policy needs to provide some guidance as to whether replacement with breakaway poles is better than protection. For those outside the clear zone guidance would be useful on whether replacement with breakaway poles might be feasible.

Research need

1. The applicability of Zegeer et al.'s models to Ontario data should be tested. In particular, it needs to be confirmed that differences in accident rate predicted by the model are due only to differences in the variables in the model.

2. The effect of replacing rigid poles by breakaway poles needs to be evaluated and examined for cost-effectiveness compared to the effect of protecting them.

References

A6.1 Coleman J., "Field Evaluations of Breakaway Utility Poles". Public Roads, pp.166-170, 1990.

A6.2 Solomon D., "Effects of Side Slope and Roadside Features of Highway Accidents: A Synthesis of Prior Research". Prepared for TRB, July 1985.

A6.3 Mak K.K. and R.L. Mason, "Accident Analysis - Break-away and Non Break-Away Poles, Including Sign and Light Standards Along Highways". U.S. Department of Transportation, Washington, D.C., 1980.

A6.4 Zegeer C. and M.R. Parker, Jr., "Effect of Traffic Features on Utility Pole Accidents", Transportation Research Record 970, TRB 1984.

A6.5 Zegeer C, Stewart R., Reinfurt D., Council F., Neuman T., Hamilton E., Miller T. and W. Hunter, "Cost Effective Geometric Improvements for Safety Upgrading of Horizontal Curves", Volume 1, Final Report. University of North Carolina Highway Safety Research Center. May 1990.

A6.6 Kurucz C.N., "An Analysis of the Injury Reduction Capabilities of Breakaway Light Standards and Various Guardrails", Accident Analysis and Prevention, Volume 16, No. 2, pp.105-114, 1984.

A7. TREES

The issues

For a variety of reasons trees exist on the roadside of many MTO roads, despite the fact that they can be hazardous to vehicles running off the road. Knowledge on what tree locations are hazardous is useful in the review and refining of policy on where trees can be permitted, and on where they need to be removed or protected.

MTO policy

The MTO Geometric Design Manual gives warrants for clear roadside recovery areas (Table D.8-1) which specify minimum unprotected clearance from the edge of the travelled way for various design speeds. The minimum for new highways is twice as much as the absolute minimum for existing highways.

Accident profile

1988 accident tabulations in Appendix C reveal that in only 53 accidents on MTO roads were trees or shrubs identified as the first object struck. This represents 1% of all fixed objects struck in single vehicle accidents.

A sample of previous research

The most definitive study was done by Zeigler (**A7.1**) who examined nearly 500 rural vehicle-tree accidents in Michigan and came up with a number of interesting findings that would be useful in setting guidelines for the location of and protection from roadside trees. Among the relevant findings were:

- Vehicle-tree accidents tend to occur on winding rural roads with vehicles leaving the pavement on the outside of the curve.
- These accidents are mainly a rural phenomenon in Michigan - 81.7% of fatal vehicle-tree accidents occurred on rural roads.
- 77% of vehicle-tree accidents on curves occurred on the outside of the curve.
- Typical accidents involved large trees within 30 ft (9.15 m) of the road.
- Most vehicle-tree accidents on curves occur on left-hand turns with downhill grades following a series of curves.

In spite of the revealing insights provided above, no single feature of the road environment accounted for all the accidents that occurred and so can be used to determine the level of risk. In particular, the distance of the tree from the road was not sufficient by itself to determine the probability of a vehicle-tree accident.

The models developed for NHTSA in a study referred to in the review for poles and posts (**A6.6**) are of some relevance since tree accidents constituted about 34% of the rigid object accidents studied and since it may be reasonably argued that trees are similar to the other rigid objects included in the accident sample. As indicated in the earlier review, the models indicate that injuries resulting from guardrail impacts are much less severe than those associated with rigid objects. The models providing guidance on estimating this benefit for any impact speed.

More recently, the study by Zegeer et al. referred to in the review for poles and posts (**A6.5**) provided models

for estimating tree accident frequency as a function of ADT, lane width, tree location and frequency and terrain type. The authors used these models to estimate, for example, that tree accidents would be reduced by 22% for every meter that trees are removed away from the road. [Comment: *Once again caution should be exercised in using accident reduction factors derived from regression models.*]

A final appraisal

The study by Zeigler suggests that roadside trees can be managed by determining the risk of vehicle-tree accidents at sites that have a history of frequent accidents and then determining the type and priority of site treatment. Nevertheless, it is unclear to what extent the Michigan findings would be applicable to Ontario. The models developed for NHTSA (**A6.6**) provide useful guidance on estimating the benefit of protecting trees with guardrail, providing the speed of potential impacts can be estimated. Zegeer at al.'s models could be used with caution in estimating the benefits of tree removal or relocation.

Assessment of MTO policy

On the basis of the literature reviewed, it is not possible at this time to make a clear determination of whether the MTO warrants for clear roadside recovery area are adequate for making decisions on accommodation or removal of trees. The basis for the numbers in the warrant is unclear; so is the basis for different warrants for existing and new highways.

Research need

In view of the relatively few target accidents, the issue of whether trees should be removed, protected or left unprotected should be addressed as part of a larger issue -- whether the warrants for clear roadside recovery area are adequate. Insights can be gained through analysis of accidents involving vehicles striking all fixed roadside objects, including trees, and by examining the current policies in the light of the models developed for NHTSA and Zegeer et al.'s models.

References

A7.1 Zeigler A.J., "Risk of vehicle-tree accidents and management of roadside trees", Transportation Research Record 1127, TRB 1987.

A8. ROADWAY ILLUMINATION

The issues

Roadway illumination should be so designed that the difference in safety risk between night and day driving is reduced to a minimum. Illumination systems usually come in two levels - full and partial. The quality and quantity of illumination is of major importance when the safety aspect is considered. Safety could be enhanced through a reduction in night-time accidents, but an increase in speed resulting from illumination could increase accident severity. Thus, knowledge of the relationship between safety and quality and quantity of lighting facilities is vital to decision-making on where illumination should be installed and how it should be designed.

MTO policy

Recommended design criteria are detailed in MTO Directive B-6, 1978. Continuous illumination is to be considered where Level of Service D exists during a dark hour on a freeway in dense urban development, or where there is adjacent high-intensity illumination, or where a centre lane is designed for continuous two-way turns. Guidelines are also given for considering interchanges, weaving areas, freeway structures and at-grade intersections. The last of these categories is covered in a separate section of this report. Another MTO directive gives extensive guidelines for the installation of high-mast lighting.

Accident profile

Accident tabulations in Appendix B indicate that about 32% of all accidents on MTO roads (42% of fatals) occur in dark hours during which only about one-sixth of all travel takes place. If only non-intersection accidents are considered, 36% of these accidents occur in darkness (43% of fatals). Of these accidents (during darkness) only about 19% are coded as occurring where there is artificial lighting. The U.S. National Safety Council's "Accident Facts" estimates that about 57% of all U.S. fatalities occur during darkness. This translates into a night fatality rate (per million vehicle miles) of approximately three times the daylight rate.

A sample of previous research

There have been several studies on the relationship between safety and lighting as well as a number of relatively recent reviews (**A8.1, A8.2, A8.3**) of knowledge on this subject. The summary below tries to extract the flavour of the knowledge that might be of relevance to roads under MTO jurisdiction.

Box (**A8.4**) conducted a before and after comparison (2 years before, 1 year after) of illumination on 5.3 miles of 6-lane urban freeway in Chicago. The route was separated into two sections. In the section with 12 ft median, the night/day accident rate ratio was reduced from 3.0 to 1.3 (4.0 to 1.0 for severe accidents) while for the section with 33 ft median this ratio was reduced from 2.9 to 2.0 (5.1 to 2.0 for severe accidents).

A number of European studies were reviewed by Cleveland (**A8.3**). (i) In England, six years of accident data revealed a remarkably consistent 30% decrease in night injury accidents following improved lighting at 64 sites covering 64.5 miles of road which had been poorly lighted. There was a strong indication that pedestrian accident experience was improved even more than this. Analysis indicated a strong net monetary benefit derivable from improving street lighting at these locations. (ii) Analysis of 900 miles of the French road system showed that the ratio of night-to-day accidents was 1.45 for unlighted roads and less than 1.25 for well lighted roads. It was concluded that a reduction of 20% in night time accidents appears achievable through

the development of a consistently well-lighted system. (iii) In a Belgian study of 800 miles of rural roads, the night accident rate on roads with an insufficient lighting system was twice as high as the day rate. On streets provided with good lighting systems, this ratio was reduced to 1.5, a reduction of 25 percent.

Box (**A8.5**) performed an analysis of lighted and unlighted routes covering a total of 203 miles of freeway with more than 21,000 accidents during the selected time periods. Data were included from cities such as Toronto, Denver, Chicago, Atlanta, Dallas and Phoenix. Most of these routes were urban with 6-lanes. Lighted freeways were found to have a 40% lower accident rate than unlighted freeways (relative to the daytime accident rate). For injury plus fatality accidents, the equivalent number is 52%.

Box (**A8.6**) examined the impact on accidents of turning off 130 lamps to save energy along a major route in Clearwater, Florida. Night time accidents increased from 68 in 1973 to 95 in 1975, while daytime accidents increased from 268 to 278. After accounting for changes in traffic volumes, a 36% increase in the night accident rate was found. [**Comment:** *This translates into a 25% decrease from turning on the lamps.*]

A final appraisal

There appears to be clear evidence that roadway illumination can reduce night accidents. For total accidents the reduction varies from 20% to 57% while for severe accidents the reduction ranges from 30% to 75%. The Table below summarizes these values:

Study details	Type*	% reduction in night accident TOTAL	SEVERE
Box (**A8.4**) freeway with 12 ft. median	B/A	57	75
Box (**A8.4**) " " 33 ft. "	B/A	31	61
Cleveland (**A8.3**) English	B/A		30
" " French	C/S	20	
" " Belgian	C/S	25	
Box (**A8.5**) Urban freeways	C/S	40	52
Box (**A8.6**) Florida	B/A	25	

* B/A refers to before and after studies while C/S refers to cross-section type studies.

After considering potential biases in both before and after and cross-section studies, it appears reasonable to expect reductions of 25 - 30% in total night accidents and 30 - 50% in night injury accidents following illumination of freeways and other principal roads. It is unclear what circumstances cause these figures to vary. In particular, it is unclear how they are affected by the level of illumination. In addition there seems to be no knowledge on conditions under which an increase in accident severity through increased speeds might be sufficient to counter-balance and expected reduction in accident frequency.

Assessment of MTO policy

Based on the literature reviewed, it is difficult to assess whether MTO policies on roadway illumination are adequate. It does appear that where illumination might to be "warranted" that it could enhance safety. Whether the safety gains can justify the cost or whether illumination might also be warranted in areas not considered under the directive is open to question and should be examined. Also policies on level of illumination and on high-mast lighting could not be assessed and should be reviewed.

Research need

It would be fruitful for the MTO to examine their own before and after experience with the installation of illumination. This would not only serve to confirm the % reductions derived from the literature, but also to examine the conditions that cause the % reduction to vary. Such knowledge, in addition to what already exists, would be useful for reviewing the roadway illumination guidelines in the directives and for setting priorities for retrofitting roads with illumination.

References

A8.1 Ketvirtis A., "Road Illumination and Traffic Safety", prepared for Transport Canada, 1977.

A8.2 "Synthesis ~~of~~ Safety Research Related to Traffic Control and Roadway Elements." Vol. 2, FHWA-TS-82-233, Dec. 1982.

A8.3 Cleveland D., "Traffic Control & Roadway Elements -- Their relationship to highway safety /revised." Chapter 3: "Illumination".

A8.4 Box P.C., "Freeway Accidents and Illumination", TRB 416, 1972.

A8.5 Box P.C., "Relationship between illumination and Freeway Accidents". Illuminating Engineering, May/June 1971, pp365-393.

A8.6 Box P.C., "Effect of lighting reduction on an urban major route". Traffic Engineering, October 1976, pp 26-27.

A9. HORIZONTAL CURVATURE

The issues

Historical evidence reveals that accidents are more likely to occur on a curved segment of roadway than on a straight segment because the curve places a higher demand on the driver and on the friction between the tire and pavement. Thus the relationship between elements of curvature and safety is a vital ingredient of decision-making on horizontal curve standards, on selection of curves for design, and on where elements of existing curvature are "sub-standard" and should be improved.

The issues were summed up by Glennon (**A9.1**) who identified the following elements of highway curves as potential candidates for research in relating highway design to safety:

A. Horizontal Alignment Elements
Radius of curvature; Length of curve; Superelevation runoff length; Distribution of superelevation runoff between tangent and curve; Presence and length of transition; Stopping site distance around curve.

B. Cross-Sectional Elements
Superelevation rate; roadway width; Shoulder width; Shoulder slope; Roadside slope; Clear-zone width.

C. Vertical Alignment Elements
Coordination of edge profiles; Stopping sight distance on approach; Presence and length of contiguous grades; Presence and length of contiguous vertical curves.

D. Other Elements
Distance to adjacent highway curves; Distance to nearest intersection; Presence and width of contiguous bridges; Level of pavement friction; Presence and type of traffic control device; Type of shoulder material.

MTO policy

The MTO Geometric Design Manual, Section C3, specifies, for various design speeds, superelevation rates and spiral lengths for circular curves of various radii starting from a minimum for the design speed. The Manual suggests that standards should be exceeded where possible, but that, under certain conditions, sub-standard design might be allowable. Curves for deflection angles larger than 5 degrees should be at least 150 m long (including 50% of the spiral length) while, for smaller deflection angles, the minimum length increases, with a recommended minimum length of 350 m for deflection angles smaller than 1 degree. Spacing and criteria for highway delineation is given in Section C 3.04 of the Ministry's Uniform Traffic Control Devices Manual.

Accident profile

1988 accident tabulations in Appendix B indicate that 3.5% of all non-intersection accidents on 2-lane MTO roads occur on curved horizontal alignment. If fatal accidents alone are considered, the comparable figure is 21%, comprised largely of single vehicle accidents. For multilane roads, comparable figures are 2.4% for all accidents and 15% for fatal accidents. In the U.S., Glennon et al. (**A9.2**) compared the accident experience of 3304 rural two-lane curve segments to that of 253 rural two-lane tangent segments and found that the average accident rate for highway curves is about three times that of highway tangents. That study also found that the average single vehicle run-off-road accident rate for highway curves was about four times that for highway tangents. A cursory examination of data tabulated in Appendix B indicates that this difference is not

very pronounced for MTO roads.

A sample of previous research

(a) Curvature and length of curve

Many studies have been conducted in an attempt to link features of highway curves to accident rates. There is general consensus that accident rates increase as curvature increases, but as Glennon (**A9.1**) points out, most of these studies suffer from the difficulty that a reliable relationship between accident rate and degree of curve is difficult to determine because curvature in not independent of other geometric elements. For example, sharp curves are usually located on lower quality highways which may have narrow roadways and shoulders, poor sight distance, and hazardous roadsides.

Perhaps the most recent and comprehensive study was one by Zegeer et al. (**A9.3**) who used a database of 3,427 curve and adjacent tangent sections on 2-lane rural roads in Washington State. The purpose was to estimate relationships between roadway characteristics and accident experience on curves and to develop these relationships into accident reduction factors. The main models found that accident experience was related to curve length, degree of curvature, ADT and pavement width (including shoulders). The models indicate that curve flattening could reduce crash frequency by as much as 80% depending on the central angle and amount of flattening.

A study conducted by Neuman, Glennon et al. (**A9.4**) used the geometric design and 3-year accident records of 3557 two-lane road sections in 4 States. Multivariate analysis indicated that, after controlling for ADT, the accident rate increases as the degree of curve increases and decreases as length of curve, road width and shoulder width increase. Using the same data base, Glennon et al. (**A9.1**) determined that the estimated reduction in the number of accidents per million vehicles for a one degree change in curvature was 0.0336. This number was used to develop a model which accounted for the change in curve length associated with changing degree of curve in determining the net accident reduction due to an incremental change in the degree of curve (**A9.5**).

Somewhat contrary to Glennon's findings, Lin (**A9.6**), in examining the accident rates of 155 horizontal curves in New York, found that the combination of curvature and traffic exposure can best account for the variation in accident rates and that, on the other hand, the combination of curvature with lane width, curve length, and superelevation rates do not yield statistically significant relationships with accident rates. A regression equation was presented for predicting accident rates from traffic volume and degree of curve.

Another study by Lam et al. (**A9.7**) used stepwise multiple regression analysis on a 3-year accident data base covering 815 accidents on 282 curved road sections to determine the influence of design parameters and traffic volume on accident rates on two-lane rural state roads. The study concluded that, related to lane widths of 10, 11, and 12 ft, degree of curve was the best predictor of accident rates, followed by average ADT. Regression equations relating accidents to degree of curve for each lane width value were presented.

(b) Superelevation

One implication of all of the above findings on curvature is that the flattening of unsafe ("substandard") curves can be more effective than increasing the superelevation. On this subject there are a number of items in the literature. In (**A9.5**) it is suggested that superelevation should be increased if design speed is below the 85th percentile speed of approaching vehicles and existing superelevation is below AASHTO maximum.

A study by Dart et al. (**A9.8**) considered 600 Louisiana accidents over 5 years and several geometric variables, using regression analysis, and concluded that pavement cross slope interacting with traffic volume had the most effect on accident rates in that roadways with relatively flat cross slopes have higher accident rates than those with greater cross slopes.

Zador et al. (**A9.9**) examined data from sites of fatal rollover accidents and comparison sites in New Mexico and Georgia, and, after controlling for both curvature and grade, found fatal rollover accident sections to have less superelevation than comparison sections. It was concluded that inadequate superelevation presents a risk that should be eliminated from the roadway system.

Finally, the Zegeer at al. study (**A9.3**) referred to earlier calibrated other models using smaller subsets of more detailed data to examine the effect of variables such as superelevation rate and the presence of spirals. The models indicate that superelevation improvements can reduce curve accidents where there is a superelevation deficiency. For example, increasing superelevation from 0.03 to 0.05 to meet AASHTO guidelines would be expected to yield an accident reduction of about 10%.

(c) Cross-Slope Break:

ASSHTO Policy limits cross-slope breaks to 8% which puts constraints on either maximum superelevation or the amount of shoulder slope. Glennon's review (**A9.1**) of research on cross-slope breaks revealed that an 8% cross-slope for stabilized shoulders intended to accommodate 4-wheel recovery is necessary. For stabilized shoulders designed to accommodate 2-wheel traversals, cross-slopes greater than 8% will not compromise safety beyond the prior decision to allow narrow shoulders.

(e) Curve Warning and delineation:

Lyles (**A9.10**) examined the effectiveness of alternative advance warning sign configurations in reducing speeds on curves and found that no sign configuration was more effective in reducing speeds than another. A before-and-after study of the placement of roadside delineators (**A9.11**) showed that curves between 5 degrees and 10 degrees with central angles between 20 and 40 degrees had significant accident reductions when delineated. [**Comment:** *It is possible that the decision to install delineators might have been based on a high recent accident count. If so, then it is likely that the benefits would have been overestimated.*]

A final appraisal

There is a considerable body of literature on safety of horizontal curves and, while these studies tend to agree that flatter curves are better, there is still no consensus on important questions such as whether flattening a substandard curve is better than improving the superelevation, and to what extent does the confounding effect of length of curve offset the benefits of flattening. The lack of consensus is perhaps due to the difficulty of inferring accident reduction factors from cross-section studies or regression models.

Assessment of MTO policy

From the literature reviewed, it appears that some guidance on maximum curve length needs to be provided to complement the MTO recommendation to use flatter curves than minimum. At the same time, the policy of recommending minimum curve lengths for small deflection angles should be reviewed since it is possible that more unsafety is the price being paid for better aesthetics. It also appears, on the basis of the literature,

that it would be prudent to review the policy of allowing "sub-standard" superelevation on resurfacing projects under specified conditions, especially in the light of considerable evidence that resurfacing increases speeds. Finally, there should be policies on curve delineation and other issues raised by Glennon (See "The issues" section above.) where these do not already exist.

Research need

It is likely that the lack of consensus is due to the difficulties of cross-section type studies, a category that fits nearly all of the studies referenced above. Since the studies reviewed appeared to be as carefully done as possible, it appears that little can be achieved by doing other such studies for Ontario data. It might be worthwhile, however, to collect and analyze before-and-after data of curve improvements on Ontario highways. The feasibility of doing so needs to be more carefully addressed prior to undertaking such research.

References

A9.1 Glennon J.C., "Effect of Alinement on Highway Safety: A Synthesis of Prior Research". TRB, April 1985.

A9.2 Glennon J.C., Neuman T.R., and J.E. Leisch, "Safety and Operational Considerations for Design of Rural Highway Curves", Report FHWA-RD-86/035. FHWA, U.S. Dept. of Transportation, August 1983.

A9.3 Zegeer C, Stewart R., Reinfurt D., Council F., Neuman T., Hamilton E., Miller T. and W. Hunter, "Cost Effective Geometric Improvements for Safety Upgrading of Horizontal Curves", Volume 1, Final Report. University of North Carolina Highway Safety Research Center. May 1990.

A9.4 Neuman T.R., Glennon J.C. and J.B. Saag, "Accident Analysis for Highway Curves", 62nd Annual Meeting, T.R.B, Washington, D.C., Jan. 1983.

A9.5 "Designing Safer Roads", TRB Special Report 214, 1987.

A9.6 Lin F.B., "Flattening Horizontal Curves on Two Lane Rural Highways", ASCE J. Transp. Eng. Mar/Apr 90.

A9.7 Lam R. and E.M. Choueiri, "Accident Rates on Curves as Influenced by Highway Design Elements Based on Investigations in the State of New York", TRB Annual Meeting 1987.

A9.8 Dart O.K. and L. Mann, "Relationship of Rural Highway Geometry to Accident Rates in Louisiana", Highway Research Record 312, TRB 1970.

A9.9 Zador P, Stein H., Hall J., and P. Wright, "Superelevation and Roadway Geometry: Deficiency at Crash Sites and on Grades", Abridgement in Transportation Research Record 1026, TRB 1985.

A9.10 Lyes, R.W., "An Evaluation of Warning and Regulatory Signs for Highway Curves on Rural Roads", FHWA 1980.

A9.11 Taylor and Foody: Curve Delineation and Accidents, Ohio Department of Highways, 1966.

A10. LEFT TURN CHANNELIZATION

The issues

Safety is an important consideration in the provision of left-turn lanes. These lanes can reduce opportunities for rear-end collisions but, in addition, can also reduce vehicle stops and delays and make the use of intersections more transparent. Seemingly, the only reason for not providing intersections with a left-turn lane is that either the right-of-way is not available or too expensive, or the road space is needed for through lanes. In principle, therefore, the decision on whether or not to provide a left-turn lane should be made by trading-off costs against safety and other benefits. Knowledge on the safety implications of left-turn lanes is vital to this decision-making process.

MTO policy

The MTO accident warrants for left-turn treatment at unsignalized intersections on two-lane highways as given in Chapter 9 (Left Turn Treatment at Unsignalized Intersections) of the Ontario Ministry of Transportation Highway Capacity Seminar Notes, 1985 is as follows:

"A left-turn storage lane may also be considered at locations where four or more left-turn related accidents occur per year or where six more occur within a two-year period, provided the accidents are of a type which could reasonably be expected to be eliminated by provision of a left-turn lane. The storage length should be 15m" (paragraph ~~3.~~2.2).

Accident profile

Accident tabulations in Appendix B indicate that 10% of all accidents on MTO roads involve turning vehicles. Of all turning accidents, about 71% occur at intersections and the vast majority involve left turns.

A sample of previous research

The conventional wisdom and current safety warrants appear to be derived largely from a before-and-after study by Hammer et al. (**A10.1**) of left turn channelization improvement at 53 intersections in California. They found a 34% reduction in accidents, although there was an increase in broadside collisions. The reduction for the 13 signalized intersections (with no left turn phase) was 17% while, for unsignalized intersections, the reduction was 48%. In the latter case, those with physically protected channelization experienced a 64% reduction in accidents while, for those with painted channelization, the reduction was 32% (This figure is higher for rural areas.). The superiority of physically protected channelization applies mainly for urban areas intersections with lower approach speeds. It was recommended that channelization should be painted rather than physically protected for approach speeds greater than 55 mph.

These results were used to suggest warrants for left-turn channelization of unsignalized intersections, based largely on the count of recent left-turn accidents. [**Comment:** *It is interesting to note that the MTO accident warrant is almost identical. The difficulty with this warrant is that a recent high accident count might be the result of random fluctuation rather than an indication of the need for channelization. This bias might well have existed in the data on which the California warrant was based, with the result that the benefits of channelization might have been overstated.*]

An ITE Guideline (**A10.2**) quotes Box (**A10.3**) in suggesting that "studies have demonstrated that accident experience is significantly reduced when left-turn storage lanes are provided at intersections of 2-way major streets". A recent ITE report (**10.4**) gave guidelines based on analysis of Kentucky data by Agent (**10.5**). These guidelines suggest that left-turn lanes might be justified at unsignalized intersections where the are 4 or more accidents/year involving left-turn vehicles; for signalized intersections the corresponding number is 5 accidents/year.

An FHWA report (**A10.6**) suggests that the provision of raised left-turn channelization at non-signalized intersections will reduce accidents by 70% in urban area and by 65% and 60% in suburban and rural areas, respectively; with painted channelization, the reductions are 30% in urban areas and 50% in suburban and rural areas. At signalized intersections, the report suggests that left turn channelization will reduce accidents by 36% with a left-turn phase and by 15% without the left-turn phase. It is also suggested that adding left-turn lanes without signals can decrease accidents by 19% on urban two-lane roads, and by 6% on multi-lane urban roads but will increase accidents by 6% on rural roads with more than 3 lanes. Adding left-turn lanes and signals will reduce accidents in the last two categories by 27 and 43% respectively.

Terry et al. (**A10.7**) conducted a before-and-after study (with control) of left-turn channelization painted on a 1.14 mile section of arterial roadway with 15 signalized intersections in California. The data showed reductions of 38% and 31% in total and injury accidents, with most of the reduction being in rear-end and left-turn accidents.

A 3-year before-and-after study of eight arterial intersections in Hamilton, Ontario by Main (**A10.8**) found that reconstruction and left-turn channelization reduced collisions by an average of 55%.

McCoy et al. (**A10.9**) inferred the safety effect of installing left-turn lanes from a 3-year cross-section study of accidents with and without left-turn lanes at uncontrolled approaches to 90 rural intersections in Nebraska. They inferred reductions in rear-end and side-swipe accidents of 60% for approaches without paved shoulders and 10% for approaches with paved shoulders. Significantly, there was no difference in left-turn accidents.

A similar type cross-section study by McCoy et al. (**A10.10**) on data for 46 urban 4-lane intersections in Nebraska found considerable reductions in rear end accidents (59% for signalized approaches without protected left-turn phase and 88% for uncontrolled approaches), side-swipe accidents (73% and 52%) and left-turn accidents (66% and 86%). At uncontrolled approaches there was a 68% increase in right angle accidents. [**Comment:** *In both Nebraska studies, it seems inappropriate to infer that differences in accidents with and without left-turn lanes is due to the presence or absence of left-turn lanes since differences in other geometric features could account for part of the observed differences in accident rates. This might explain some of the apparent inconsistencies, e.g., that for the rural approaches there was no difference for left-turn accidents as opposed to a considerable difference for the urban approaches.*]

Jorgensen et al. (**A10.11**) estimate that left-turn lanes reduce accidents by varying amounts depending on whether the intersection is rural or urban, whether it is 4-legged, cross or tee, and whether or not signals are added as well. Increases in accidents were found for adding turn lanes without signals at four-legged (6%) and with signals at Tee (42%) rural intersections.

At least one other study (David et al. (**A10.12**)) concluded that left-turn lanes are not always good for safety, but this finding might be a result of biased analysis. A cross-section study of 2-phase, four-legged intersections found that, for similar volumes, those with left-turn lanes had "significantly" higher accident rates than those without, although there was no significant difference in turning accidents. The authors incorrectly infer that the provision of left-turn channelization without a third phase will increase the accident rate. The authors also found, based on a similar type of comparison, that the introduction of a third phase (with the left-turn lanes) reduces accidents "although each additional phase lengthens the overall cycle and thereby increases delay".

A final appraisal

It appears widely recognized and supported that left-turn lanes are generally good for safety. At the same time, it is difficult to ascertain any guidance from the literature as to the conditions under which a left-turn lane should be provided. Therefore, it may be that opportunities for extracting safety benefits from left-turn lanes are foregone in Ontario.

Assessment of MTO policy

It may be that the MTO accident warrant for left-turn lanes might be flawed. (See comment after the summary of reference (**A10.1**) above.)

Research need

What appears to be needed is a clear procedure for specifying what the quantitative descriptors of the situation are and how on the basis of local conditions a rational decision should be made. Such a procedure does not at present exist. Therefore, we recommend that the knowledge presently available be critically reviewed, summarized, and supplemented by Ontario experience, and that all useful information be cast into the form of a usable procedure.

References

A10.1 Hammer C.G. and T.N. Tamburri, "Evaluation of Minor Improvements, Part 5, Left Turn Channelization", California Division of Highways, May 1968.

A10.2 ITE Journal, July 1987.

A10.3 Box P.C., "Traffic Control and Roadway Elements - Their Relationship to Highway Safety: Chapter 4 Intersections", Highway Users Federation for Safety and Mobility, 1970.

A10.4 Institute of Transportation Engineers, "Final Report on Guidelines for Left-Turn Lanes". Committee 4A-22, July, 1990.

A10.5 Agent K., "Warrants for Left-Turn Lanes". Transportation Quarterly, Vol.37, No.1, pp.99-114, 1983.

A10.6 Lee J., "Developing Left-turn guidelines for priority Intersections in the State of Kansas". University of Kansas Centre for Research, Report FHWA-KS-78-1, 1978.

A10.7 Terry D.S. and A.L. Kassan, "Effect of Channelization on Accidents", Traffic Engineering, Dec. 1968.

A10.8 Main M., "Four Underutilized Collision Reduction Measures", Roads and Transportation Association of Canada Monograph, September 1982.

A10.9 McCoy P.T., Hoppe W. and D. Dvorak, "Cost effectiveness evaluation of turning lanes on uncontrolled approaches to rural intersections". Nebraska Department of Roads, Report No. TRP-02-15-84, October 1984.

A10.10 McCoy P.T. and M.S. Malone, "Safety Effects of Left Turn Lanes on Four Lane Roadways", Paper No. 880035, Transportation Research Board 68th Annual Meeting, Washington, D.C., January 1989.

A10.11 Jorgenson and Associates and Westat Research Analysts, "Evaluation of Criteria for Safety Improvements of the Highway". Report PB-173-822, Office of Highway Safety, U.S. Bureau of Public Roads, 1966.

A10.12 David N. and J. Norman, "Motor vehicle accidents in relation to geometric and traffic features of highway intersections". U.S. Federal Highway Administration.

A11. MEDIANS AND MEDIAN BARRIERS

The issues

Medians serve a variety of functions: to provide a safety buffer from opposing traffic; to provide a recovery area for out-of-control vehicles; to provide a storage area for emergencies; to facilitate speed change lanes for left-turns and u-turns; to reduce headlight glare. Since all of these functions can be linked to safety, the relationship between median design and accident occurrence is an important ingredient of effective safety management of MTO roads. Specific design issues are how to select median width and sideslope, whether the median should be flushed, raised or depressed and, in each case what is the effect of installing median barriers of a given type.

MTO policy

The MTO Geometric Design Manual (Section D.6) indicates current median design practice for urban and rural freeways and arterials. For urban freeways it is common to use median barriers and flush or raised medians. Medians have widths of 6 m for 4-lane freeways and 7.5 m for multi-lane freeways. Concrete barriers are used with flushed medians while double steel-beam barriers are applied with raised medians. This Manual further indicates that on rural freeways a 22 m wide depressed median allows for practical sideslopes of 6:1, obviates the need for median barriers, and allows for addition of 2 future lanes. For narrower medians, a median barrier is warranted if the AADT (thousands) is 5 times the median width (m) for favourable conditions or 3.25 times the median width for unfavourable conditions such as icing, difficult terrain, high speeds or many cross-median accidents.

More specific guidelines, which perhaps supercede those in the Geometric Design Manual, are given in the Ministry's Design Manual for Traffic Barriers, Energy Attenuators & Light Poles and in a related directive (PHY B-221). These relatively new (1988) guidelines indicate that barriers are warranted for medians less than 10 m wide on highways with AADT larger than 20,000. (The threshold varies from 20,000 to 30,000 for widths of 6 and 10 m.). Provision is made for installing barriers regardless of traffic volumes where median crossover accidents are identified as a problem. The "optimum median concept" is said to be a median width of 10-15 m with 10:1 slopes. The new policy also provides for the IBC Mark VII barrier to be considered as an alternative to concrete barrier on projects where the median width is greater than 6 m.

In the U.S., median barriers, according to AASHTO, are normally installed on freeways when restriction is apparent in the median width, or when ADT exceeds 60,000, or when annual cross-median accidents are high (>0.46/mile for total or >0.12/mile for fatals). It has been usual practice to use cable barriers for median widths of 16 ft. or more and concrete or beam barriers for narrower medians.

Accident profile

The best indication of median related accidents is accidents occurring on the left side of divided highways which, according to accident tabulations in Appendix B, constitute about 6.3% of all accidents on MTO roads. For about 50% of such accidents, the impact occurred off the roadway. Of the off-roadway accidents about one-third are coded as occurring on roads that are divided and have a restraining barrier. (Other accidents include those on express and collector roadways, some of which have barriers.) Table B9 in Appendix B provides some interesting insights on accident experience for various median designs.

A sample of previous research

The summary below is divided into 2 areas: median width and median barriers.

(a) Effect of median width on safety

Results of a Kentucky study by Garner et al. (**A11.1**), support the conventional belief that wider medians are safer medians. Cross-sectional data showed that total median-involved accidents to vehicles that crossed the median decreases as the median width increases. There was a linear decrease in total accident rate per 100 MVM from 90 at 10 ft. median width to 55 at 60 ft. median width. On the basis of an apparent "leveling off" between 30 and 40 ft., the authors suggested a minimum median width of 40 ft. It was found that the beneficial effects of wide medians can be completely negated by steep slopes. Deeply depressed medians were observed to have a higher accident severity rate. On this basis, a minimum median slope of 4:1 was suggested.

Raised medians in the study (20 to 30 ft.) were found to have several disadvantages not entirely explained by narrower width. Raised medians seem to have a higher number of cross-median accidents. It was hypothesized that since raised medians had a sod curb a few feet from the edge of the pavement, many drivers would hit this curb and overreact, causing an accident. [**Comment:** *It is possible that raised medians might be installed where there are likely to be a high frequency of cross-median accidents to begin with. Thus one cannot relate the frequency of cross-median accidents to the presence or absence of raised medians.*]

A number of studies (**A11.2, A11.3, A11.4**) have failed to find a definite relationship between accident rates and width of various types of medians. Although the overall superiority of wider medians could not be shown, it was apparent that cross-the-median and head-on-collisions were lower for wider medians.

Hutchinson (**A11.5**) studied encroachment on several medians and found that steep median slopes (4:1) cause driver overreaction and vehicle control problems. He concluded that an absolute minimum median width of 30 ft. is required under ideal conditions of mild slopes and no median obstacles and estimated that a 40 ft. depressed median with 10:1 slopes would allow more than 90 % of all encroaching vehicles to recover safely.

(b) Effect of median barriers on safety

A before-and-after study by Johnson (**A11.6**) on 26.6 miles of roadway with cable barriers and 27.6 miles of roadway with beam barriers found that median barriers were effective in preventing cross-median accidents with the almost total elimination of fatal ones. However, largely because of an increase in fixed object accidents, there was a 32% increase in overall accident rates for cable barriers and a 20% increase for beam barriers. Also, injury and fatal accidents combined increased after barrier installation. At the more rigid beam barriers the increase (30%) was almost twice that for cable barriers (18%). The rate of accidents involving the median decrease substantially with increasing median width in the case of a beam barrier and decreases slightly with increasing width in the case of cable barrier. However, regardless of median width, the beam barrier, as might be expected on the basis of their rigidity, tended to have relatively fewer reportable collisions.

A final appraisal

(a) Effect of median width on safety

In a valid cross-section study, the only variable between locations, other than traffic volume, should be median design, which tended not to be the case in the studies reviewed. Thus, local roadway peripheral and

environmental factors might also explain differences in accident rates between sections. This concern might explain the variety in the findings for the studies reviewed. Finally, it should be noted that the studies sampled are rather dated. The extent to which they are still applicable is unclear.

(b) Effect of median barriers on safety

The one before-and-after study cited appears to give valid results but it is rather dated, so its applicability to Ontario in the 1990's is questionable, given the considerable advances in median barrier design in the 25-30 years since that study.

Assessment of MTO policy

If we assume that the studies cited are valid, then one can say that the MTO warrant guideline of not requiring a barrier for widths larger than 15 m is adequate. It seems clear that requiring barriers for widths less than 10 m is good for safety but, on the basis of the literature, it is difficult to quantify these benefits and to assess this policy with respect to cost-effectiveness. In addition, the guidelines for median design for urban freeways and arterials and for rural arterials could not be assessed on the basis of the literature. The accident profiles given in Appendix B suggest that a review of MTO policy on median design might be appropriate.

Research need

Any research on median barriers requires that first a detailed study be conducted of target accidents involving median design. If these are sufficient, it might still be worthwhile to review policies on median width and protection for safety implications and cost-effectiveness.

References

A11.1 Garner G. and R. Deen, "Elements of median design in relation to accident occurrence". Highway Research Record 432, 1973.

A11.2 Hurd F.W., "Accident experience with traversable medians of different widths". HRB Bulletin 137, pp. 18-26, 1957.

A11.3 Crosby J., "Cross-median accident experience on the New Jersey turnpike". HRB Bulletin 266, pp. 63-67, 1960.

A11.4 Garner G., "Accidents at median crossovers". Highway Research Record 312, pp. 55-63, 1970.

A11.5 Hutchinson J.W., Scott W.A. and T.W. Kennedy, "Medians of divided highways". Highway Research Board Bulletin 34, 1963.

A11.6 Johnson R., "Effectiveness of median barriers". Highway Research Record 105, 1966.

A12. DRAINAGE STRUCTURES

The issues

Aspects of drainage structures, e.g., culvert ends, curbs and ditches, can present a safety hazard if not properly designed and protected. Thus knowledge on the safety implications of relevant aspects of drainage structure design, is useful in the review and formulation of design and maintenance standards.

MTO policy

Design standards for aspects of drainage structures that might present safety standards are given in appropriate drainage design manuals.

Accident profile

According to the accident tabulations in Appendix B, in approximately 2% of accidents on MTO roads, culverts, curbs or ditches are the first fixed objects struck. These account for approximately 20% of all fixed object accidents. About 66% of these accidents involve ditches while very few involve culverts. By way of comparison, on U.S. Federal-aid roads, accidents with drainage structures such as curbs, ditches, embankments (hard and soft), culverts, and walls were found to comprise 4.6% of all accidents (9.3% of fatals). (See Robertson (**A12.1**).) In this case, curb accidents dominated (31.5%). Drainage structure accidents were overrepresented on grade and curves, at night, and in adverse weather.

A sample of previous research

Dixon et al. (**A12.1**) used data from more than 1469 culvert-related accidents in Texas to develop a procedure for the evaluation of improvements to these structures. A probability model was used to measure the hazard potential of individual culverts based on ADT and the width, length, and distance from roadway of the hazard. Improved design (protected and unprotected cross-drain and driveway culvert installations) was then subject to benefit/cost analysis. Among the main results were:

- culvert ends do not require special end treatments for 36" diameter and 50000 ADT, for 42" and 20,000 ADT and for 60" and 10000 ADT.

- driveway culvert ends need not be provided where full shoulders are present for 30" diameter pipe and 3,000 ADT, for 24" and 1,600 ADT. For larger sizes treatment is warranted if the pipe end is inside the clear zone.

- high priority for safety expenditure should be assigned to on-roadway factors (e.g., shoulder improvement, signing, marking and delineation) rather than to arbitrary drainage structure improvement programs to, e.g., slope the ends of driveway culverts and install grates on cross-drain culverts.

The study by Dixon, it seems, focused on culvert accidents, which, as indicated earlier are relatively scarce. Thus, this study may not be totally relevant when the issue is drainage structure safety in general, particularly since. This is perhaps why Dixon's conclusions are somewhat in contrast to those of a 1975 study for Transport Canada (**A12.3**) which found, based on a limited sample of Ontario data, that, among roadside hazards, the product of average accident cost and accident frequency was highest for culverts and curbs. This was largely due to the high cost of drainage structure accidents at that time. It seems unreasonable to assume that those

relative costs still apply.

A final appraisal

The findings by Dixon that drainage structure improvements are not a high priority in terms of cost-effectiveness can be extended to suggest that research on the safety of drainage structures should be given low priority. That there is relatively little research in this area seems to support this suggestion. However, the Transport Canada study, though not current, would indicate that caution should be exercised before concluding that research on drainage structure safety should be given low priority.

Assessment of MTO policy

On the basis of the appraisal and of the relatively few target accidents, it would appear that, once MTO standards are in accord with standard design practice, they would be adequate and not in urgent need of review.

Research need

Given the small number of target accidents, and the current knowledge on what is sound design practice, it is unlikely that research in this area can be cost-effective. If there is a need to assess the cost-effectiveness of treating unsafe culvert ends, available models, such as those developed for Transport Canada, (**A12.3**) should suffice.

References

A12.1 Robertson H.D., "Magnitude and Severity of Drainage Structure Related Highway Accidents". Transportation Research Record 1195, TRB 1988 .

A12.2 Nixon J.F. and D. Hustace, "Analysis of Safety Benefits Expected Through Modifications in Drainage Structure Design". Transportation Research Record 806, TRB 1981.

A12.3 Hallett P., Hauer E. and C. Jen Liew, "Modelling technique for treating roadside hazards", Presented at the RTAC Annual Conference, September 1975.

A13. BRIDGES

The issues

Ideally, a bridge should be at least as wide as the approach roadway. However, many narrower bridges exist, since the costs associated with bridge structures are very high. An FHWA report by Rowan et al. (**A13.1**) identified a number of relatively low cost treatments for narrow bridges. These include signing and marking, delineation of roadway and bridge-rail, installation of approach guiderail, and widening. This range makes it vital that, in the design of new bridges and in decision-making on upgrading existing narrow bridges, knowledge of bridge safety and treatment effectiveness be used in making tradeoffs between bridge cost and safety and in deciding how to mitigate accidents resulting from narrow bridges.

MTO policy

MTO policy in bridge width is outlined in the Ontario Bridge Code (**A13.2**). According to the code, the number of lanes, lane width and median width should always be the same as for the approach roadway. However, shoulder widths of 0.5 m narrower than the approach shoulder width are permitted, provided the bridge shoulder is at least 1 m wide. For long bridges (>200 m) the maximum shoulder width is 1.5 m. Full width shoulders (as wide as that approach shoulders) is recommended for short bridges (<10 m) and where the approach has barriers or curbs.

Accident profile

In Ontario, about 1% of all accidents (2% of fatals) occur at overpasses and bridges. It is unclear how many more accidents occur in the vicinity of bridges.

A sample of previous research

Turner et al. (**A13.3**) examined accidents at 960 bridge sites on Alabama State roads and found that accidents on bridge approaches and departures occurred at more than twice the rate as on the adjacent roadway. This increase was found to extend approximately 0.35 miles (573 m) from the bridge ends. The data also indicated that only of about 12% of accidents occurring on bridge structures are coded as bridge hits (rail or abutment). Another 3% are labelled as hitting guiderail.

Mak (**A13.4**) reviewed literature prior to 1985 on bridge safety and found general consensus that bridges of similar width have higher accident rates on roadways with no approach shoulders than those on roadways with approach shoulders. For roadways with approach shoulders, accident rates tend to be highest for bridges with greater than 50% shoulder width reduction. It was suggested that the clear bridge width should be at least as wide as the approach travelled-way width. Desirably, for bridges on two-lane highways, bridge width should be a minimum of 6 ft. wider than the travelled way width and include shoulders that are at least half of the width of those on the approach roadway. The evidence suggests a desirable minimum 2-lane bridge width of 33 ft. consisting of two 12 ft. lanes, a 3 ft. left shoulder and a 6 ft. right shoulder.

The studies summarized below include a sample of those reviewed by Mak.

A cross-section study by Cirillo (**A13.5**) used traffic, geometric, and accident data for 2,000 miles of Interstate highway in 16 States (1961 to 1963) and found that accident rate increased with longer structure length. For

structures 200 ft or longer, the accident rate increased more sharply for lower lateral clearances. For structures 150-199 ft long, the accident rate was similar for all lateral clearances. At lengths of 300-499 ft, the difference in accident rate between clearances less than 6 ft and clearances 9 to 12.9 ft was statistically significant at the 0.10 level. It was concluded that wider minimum lateral clearances reduced accident rates.

Turner (**A13.6**) used manual correlation and regression analysis to relate accident rate to roadway and bridge variables using a database consisting of 2,849 accidents on 2,087 two-lane bridges in Texas over a 4-year period (1975-1978). The final regression equations, which related accident rate per million vehicle passages to bridge relative width (RW), indicated that for RW greater than +6 ft, the accident rate is fairly constant at approximately 1 accident per 10 million vehicular passages. Between relative bridge widths of -4 and +6 ft., the increase in accident rate with decreasing RW is relatively steep. For RW less than -4 feet, the decrease in accident rate is contrary to intuition. [**Comment:** *Perhaps this is a result of using cross-section type analysis to infer causes for accident rate differences. Indeed, as the author states, factors such as bridge length and type, curbs, approach alignment, pavement surface condition, and so forth, were not included because definitive information on their safety effects was unavailable in the published literature.*]

Two before-and-after studies shed some light on effectiveness of narrow bridge treatments. Woods et al. (**A13.7**) found that treatment consisting mainly of installing W-section approach and bridge rail on narrow bridges in Texas reduced annual accidents involving the side of a bridge from 1.14 to 0.12 per 1,000 vehicles and those involving the end of a bridge or approach rails from 1.14 to 0.37 per thousand vehicles. It should be noted that these results are based on a total of only 24 accidents in relatively short before and after periods.

The second before-and-after study was by Gunnerson (**A13.8**) who examined 353 accidents at 72 narrow bridges in Iowa over a 12-year period (1948 to 1959) and found that accident rates increased sharply at the 65 narrow (<24 ft.) bridges where only the approach travelled way width was widened (to 24 ft.). At the 7 bridges where both the approach roadway and the bridge width were widened to the same width (30 ft), the accident rate decreased.

A final appraisal

It seems clear from the literature that narrow bridges are bad for safety and that solutions such as widening and low cost treatments can improve safety at these locations. The literature also provides some guidance on what is a desirable standard for bridge width. What is unclear is what factors should be considered, and how they should be considered, in specifying and prioritizing improvements to existing narrow bridges and in determining whether it is cost-effective to design new bridges to less than the desirable standard. In both cases, the fundamental question -- Are the safety gains worth the cost? -- cannot confidently be answered on the basis of knowledge provided in the literature.

Assessment of MTO policy

It is unclear whether current MTO policy is guided by an explicit balancing of safety and economics.

Research need

A useful research programme would include (a) an evaluation of safety at Ontario narrow bridges (b) an evaluation of the safety effectiveness of various treatments (c) an examination of current policy on bridge shoulder width to determine whether the savings achieved by constructing narrow bridges outweigh any increased accident costs.

References

A13.1 Ministry of Transportation and Communications, Ontario, "Ontario Highway Bridge Design Code", 1983.

A13.2 Rowan et al., "Safety Design and Operational Practices for Streets and Highways", Prepared by Texas Transportation Institute for FHWA, Technology Sharing Report 80-228, May 1980.

A13.3 Turner, D.S. and Rowan, N.J. "Investigation of Accidents on Alabama Bridge Approaches". Transportation Research Record 847, 1982.

A13.4 Mak K.K., "Effect of Bridge Width on Safety: A Synthesis of Prior Literature". TRB State-of-the-art report, 1985.

A13.5 Cirillo, J.A., "Safety Impacts of RRR Projects". Public Roads, Vol.48, No 3, December 1984, pp.103 - 107.

A13.6 Turner D.S., "Prediction of Bridge Accident Rates". ASCE Journal of Transportation Engineering, Vol.110, No.1, January 1984.

A13.7 Woods D.L. et al., "Remedial Safety Treatment of Narrow Bridges". Traffic Engineering, March 1976.

A13.8 Gunnerson, H.E., "Iowa Narrow Bridge Accident Study". Highway Research Abstracts, Vol. 31, No.7, July 1961.

A14. SIDE-SLOPES AND EMBANKMENT GUIDERAIL

The issues

The rate and severity of run-off-road accidents can be influenced by the steepness of side-slopes. The quantification of this effect is of vital importance in the design of side-slopes and decision-making on improving hazardous slopes by flattening or rounding, or by installing guiderail.

MTO policy

The MTO Design Manual for Traffic Barriers specifies that guide rail on embankments is warranted only where the combination of height and slope of the embankment is more hazardous than the barrier system. The Manual indicates that generally, a 2:1 slope is considered as hazardous as a guiderail installation, but that the "breakeven" should depend on a number of factors. Indeed, the embankment protection warrant nomograph considers factors such as design speed, horizontal curvature, shoulder width, gradient, and the cross-section beyond the toe of the slope in deciding whether a slope is adequate, or flattening or guide rail is required. On undivided highways, guiderail is not required for fill heights less than 3 m or slopes of 3:1 or flatter. Comparable numbers for divided highways are 2 m and 4:1. These policies are being reviewed by Queen's University under an MTO contract (**A14.1**).

Accident profile

Tabulations in Appendix B indicate that single vehicle accidents not involving moving objects constitute about 42% of all accidents on MTO roads. Of these, about 28% are coded as "ran-off-road", a category that accounts for about 21% of all fatalities on MTO roads. It is likely that there are more accidents involving a vehicle traversing the side slope since many single vehicle accidents are coded according to the roadside object struck.

A sample of previous research

Graham and Harwood (**A14.2**) studied the effect of clear recovery zones and different sideslopes and found that steeper sideslopes are associated with an increase in single vehicle and run-off-road accidents for all ADT levels and road types.

Perhaps the most significant research was by Zegeer et al. (**A14.3**) who examined data for 595 rural roadway sections in 3 States (Alabama, Michigan and Washington) totalling 1,777 miles. A log-linear regression model was calibrated to relate the single vehicle accident rate (per 100 MVM) to ADT, side-slope ratio, lane width, shoulder width and roadside recovery distance. The model indicates that the single vehicle accident rate decreases steadily as side-slope becomes flatter, with a levelling off at a side-slope of 7:1. On this basis accident reduction factors were suggested for various before and after side-slope ratios. [**Comment:** *To infer accident reduction factors from a regression model is clearly inappropriate in this case since flatter side-slopes might be associated with better geometric and operational features, many of which are not accounted for in the model. An indication of this difficulty is that only about 19% of the variation in single vehicle accidents is explained by the model!. This is low even if one considers that accident counts are subject to random fluctuation.*]

On the question of when to install guiderail, perhaps the most recent relevant safety research is a 1980 California study (**A14.4**) which used regression analysis to, in effect, compare the severity of guiderail accidents to that of vehicles going over embankments. It was found that, as a result of guiderail improvements over the

years, the "equal severity" line could be shifted so that guiderail should only be considered for fill slopes steeper than 3:1. For slopes of 2:1 and 1.5:1, guiderail should be considered for embankments higher than 12.5 ft and 10 ft, respectively. [**Comment:** *Caution should be exercised in using these results: (a) the data used pertain to a mixture of guiderail designs, vehicle speeds and road types; thus the results might not be valid for jurisdictions with a different mixture (b) Seat belt use was uncommon in California at the time; in fact, many of the severe embankment accidents involved ejections. Thus the applicability of the results to a jurisdiction with high seat belt usage is questionable. (c) Severity was "normalized" on the basis of an assumed ratio 107:3.4:1 for severity (cost) of fatal, injury and PDO accidents. Clearly the equal severity line is sensitive to assumptions on relative severity of different accident types. (d) Finally, these results address the issue of equal severity and not cost-benefit.*]

A final appraisal

It is difficult to argue against a thesis that flatter side-slopes are safer. Yet, two important questions remain. The question of how much is safety affected by flattening or steepening side-slopes is difficult to resolve since there is relatively little before-and-after experience and since results inferred from cross-section type studies such as Zegeer's can only, for reasons mentioned above, constitute an upper bound. Also, the question of when guiderail should be installed needs to be resolved for individual jurisdictions and needs to be constantly reviewed because of changing vehicle and guiderail standards. Modelling techniques that relate safety to predicted encroachment frequency and probability of encroachment resulting in impact appear promising. The Queen's University study (**A14.1**) is developing this approach.

Assessment of ~~MTO~~ policy

The 1980 California study would indicate that these standards should be reviewed since it might be possible that too much guide rail is being warranted, but for reasons mentioned above, those findings are not applicable to Ontario. Nevertheless, since current MTO embankment protection warrants are at least 8 years old, it is perhaps timely that a review is underway.

Research need

Ontario research on the two questions raised in the final appraisal above is clearly needed in view of the potentially large safety benefits and the many factors that cause results to be jurisdiction-specific. The feasibility of doing this research on the basis of accident experience needs more careful examination in view of the difficulties of cross-section studies and the practical problems of before-and-after studies. At present, the modelling approach adopted in the Queen's University appears adequate. It is worth noting that Kentucky has recently conducted a similar exercise -- adopting existing models used to develop warranting guidelines for clear zones and embankments based on accident severities and costs representative of Kentucky conditions (**A14.5**).

References

A14.1 Stewart A. and K. Rose, "Benefit Cost Analysis of Flatter Embankment Slopes". Department of Civil Engineering, Queen's University, November 1990.

A14.2 Graham J and D. Harwood, "Effectiveness of Clear Recovery Zones". NCHRP Report 247, TRB, 1982.

A14.3 Zegeer C. et al. "Accident Effects of Sideslopes and other Roadside Features on Two-lane Roads".

TRR 1195, 1988.

A14.4 Tye E.J., "Embankment Guiderail". California Department of Transportation Report FHWA-CA-TE-80-2, 1980.

A14.5 Pigman J. and K. Agent, "Guidelines for Installation of Guardrail", Transportation Research Record 1302, 1992.

A15. TRAFFIC CONTROL SIGNALS -- INSTALLATION

The issues

The decision to install a traffic control signal at an intersection is, as is the case in Ontario, based on warrants which specify minimum levels of traffic volume and/or "correctable" accidents to justify an installation. In all cases, it is desirable that there be no degradation in safety after the installation. Thus, knowledge on the safety impact of traffic signal installation is vital to the review of warrants and to the allocation of resources to signal installation.

Accident profile

Accident tabulations in Appendix B indicate that about 21% of all accidents on MTO roads occur at intersections. Of these, approximately 40% occur at signal controlled intersections.

MTO policy

Warrants for traffic signal installation are detailed in a recent (1989) MTO Manual "Traffic Control Signal Timing and Capacity Analysis at Signalized Intersections", Section 3. Signals are warranted by traffic volumes, delay, or safety or some combination of these. The safety aspect of the warrant is satisfied if 15 or more "correctable" accidents occurred over a 3-year period and the trial of less restrictive remedies have failed.

A sample of previous research

In 1968, Box et al. (**A15.1**) reviewed nearly 40 studies on the safety of signals and concluded that the "findings were confusing and inconsistent". On this basis, he concluded that "the decision to retain or abandon the accident warrant may well have to be resolved in the area of philosophy rather than factual evidence". A review by Persaud in 1987 for the MTO (**A15.2**) found that little has changed. The warrants, such as the current MTO warrant, remain essentially unchanged. And research findings remain inconsistent. Persaud found that, while much has been published on the subject, there is little consistency in the results. There is, however, some empirical support for what intuition suggests -- that signal installation is likely to increase rear-end accidents and decrease right angle accidents. Depending on which type of accident predominates at an intersection, it seems likely that, on balance, signals could be either good or bad for safety and this might explain the variety of results on the overall impact of signal installation.

The other possible explanation for the lack of consensus is that the overall safety effect of signal installation must depend on a variety of factors, a recognition that prompted some studies to try identify the circumstances in which signal installation might be good for safety. For example, the safety warrant for installing signals, such as MTO's, and MUTCD's, implies that signals might be good for safety if accidents exceed some number. However, as pointed out in Persaud's report, what evidence there is to support this belief appears to be tainted by statistical pitfalls in the analyses. The RTAC warrants (**A15.3**) allow signals to be warranted by a combination of safety and efficiency and even for warrant "priority points" to be deducted if an installation would be bad for safety. But, as pointed out in Persaud's report, the allocation of safety priority points is not on solid foundation.

The literature as well as practitioners suggest that signals are rarely installed on account of a safety warrant, but mainly on the basis of traffic volumes. In many installations, no warrants are satisfied, and the findings

of many studies has led traffic engineers to the very convenient belief that only warranted installations are good for safety. Once again, as Persaud demonstrates, most of these studies are fraught with methodological problems which make their findings questionable.

A final appraisal

A recent FHWA study (**A15.4**) identified the U.S. warrants for signalization, which are similar in principle to MTO's, as an issue having a significant need for additional research. On the basis of the concerns raised above, we concur. Part of the reason for this need is that currently little is known about the safety implications of traffic signal control at an intersection. As a result, little substantive guidance is provided to professionals on this matter.

Assessment of MTO policy

For reasons alluded to above, accident warrants based on the count of accidents over some time period, such as MTO's is, are not adequate. The MTO accident warrant needs to be reviewed. This it appears has been recognized by MTO since we understand that a review is in progress.

Research Need

There appears to be an opportunity for safety gains by doing research into providing guidance on the safety implications of traffic signal installation and it should be pursued. The aim of such research would be to enable the MTO to estimate for a specific site what is the expected safety effect of conversion to traffic signal control. With sound knowledge on this aspect, all the impacts of a proposed conversion can then be rationally weighed in a cost/benefit resource allocation procedure that could, in principle, replace the current warrants.

References

A15.1 Box P.C. and W. Alroth, "Assembly, analysis and application of data on warrants for traffic control signals, Part III". Traffic Engineering, January, 1968.

A15.2 Persaud B.N., "Review of knowledge on the safety impact of traffic signal installation". Report prepared for the Ontario Ministry of Transportation, Traffic Management and Engineering Office, December 1987.

A15.3 Roads and Transportation Association of Canada (RTAC), "Uniform Traffic Control Devices for Canada. Part B, Division 2, "Installation warrants for traffic control signals". 3rd. Edition, 1976.

A15.4 Shapiro P.S., Upchurch J., Loewen J., and V. Siaurusaitis, "Identification of needed traffic control device research". Transportation Research Record 1114, pp.11-21, 1987.

A16. TRAFFIC CONTROL SIGNALS -- LEFT-TURN PROTECTION

The issues

The alternative forms of left-turn protection at a traffic signal are permissive left turns (P), or when a separate phase is warranted, protected only (PO), or protected/permissive (PP). It is generally accepted that PP has less delay but more accidents than PO. A decision on the type of left-turn protection should properly be made by trading-off the safety repercussions against the operational effects.

MTO policy

Warrants for left turn protection at traffic signal installations are detailed in a recent (1989) MTO Manual "Traffic Control Signal Timing and Capacity Analysis at Signalized Intersections", Section 11. Safety does not appear to be an explicit consideration.

Accident profile

We have found no information on accidents associated with left-turn protection at signalized intersections on MTO roads.

A sample of previous research

Agent and Dean (**A16.1**) report that, following introduction of separate left-turn (PO) phases at 24 intersections, an 85% reduction in left-turn accidents was accompanied by a 33% increase in rear-end accidents, producing a 15% reduction in total accidents. On this basis, one might expect that when some protection is removed from PO (to provide PP) there will be an increase in left-turning accidents. A before-and-after comparison of 17 intersections so altered (**A16.2**) indicates a 6 fold increase in left-turning accidents and a 20% increase in other accidents. The same study examined the effect of changing 17 signals from PP to fully protected (PO); the number of left-turn accidents decreased by a factor of 7, but the number of other accidents almost doubled. More recently, Agent (**A16.3**) found that left-turn accidents increased about four-fold at 11 approaches after conversion from protected to permissive phasing; total accidents, however, did not change.

All of the studies mentioned so far are of the simple before-and-after type. So, it seems likely that all of the reported safety changes might be exaggerated because of a statistical pitfall that plagues this type of study. We have also reviewed a few of the studies of the cross-section type (e.g. David and Norman (**A16.4**), Upchurch (**A16.5**)), in which differences in safety at intersections with different types of left-turn protection are assumed to be due to differences in protection. As indicated in several parts of this report, this assumption is not a good one and will lead to incorrect results. In both cross-section studies mentioned, there were a number of paradoxical results.

A final appraisal

The decision on what type of left-turn protection to provide at traffic signals is very sensitive to assumptions about the expected safety changes. There does seem to be a consistent indication that the protected mode of control (PO) is the safest one while the permissive (P) mode is the most unsafe. However, numerical

estimates of safety cannot be provided until methodologically sound analysis is performed.

Assessment of MTO policy

It would appear worthwhile to pursue the possibility of making safety an explicit consideration in the warrants for left-turn protection.

Research need

As indicated above, current information on the safety implications of alternative left-turn protection forms is sketchy and clouded by uncertainty. New research to correctly estimate these expected changes in the context of MTO roads seems vital.

References

16.1 Agent K. and R. Dean, "Warrants for Left-Turn Phasing". Transportation research record 737, pp.1-9, 1979.

16.2 Institute of Transportation Engineers, Florida Section, "Left-turn phase design in Florida", ITE Journal, 52:9, pp.28-35, 1982.

16.3 Agent, K., "Guidelines for the use of Protected/Permissive Left-Turn Phasing". ITE Journal, pp. 37-42, July 1987.

16.4 David N. and J. Norman, "Motor vehicle accidents in relation to geometric and traffic features of highway intersections". Federal Highway Administration, 1975.

16.5 Upchurch J., "A Comparison of Left Turn Accident Rates for Different Types of Left Turn Phasing". Paper No. 910222, Transportation Research Board 70th Annual Meeting, January 1991.

A17. PAVEMENT CONDITION AND RESURFACING

The issues

It is reasonable to believe that skidding and hydroplaning accidents are associated with skid resistance properties of a pavement surface. However, improvement of skid resistance could be counter-balanced by an increase in dry pavement accidents resulting from increased speed not only on the improved sections but also on surrounding ones. The main questions of interest are what level of skid resistance and what type of accident pattern would make skid resistance improvement beneficial to overall safety.

MTO policy

Guidelines for determining when to resurface are contained in the MTO Pavement Design and Rehabilitation Manual (1990). Essentially, a pavement is rehabilitated when the pavement condition index (PCI) reaches a lower threshold value that depends on a number of factors including road classification. The pavement condition index is derived from an index of riding comfort (RCI) and an index of stress condition (DMI). Skid resistance is only indirectly considered in that it is likely to be strongly correlated with RCI and DMI. However, a pavement can warrant resurfacing on the basis of skid resistance only if it is determined that a blackspot has resulted from a high frequency of accidents correctible by resurfacing.

Accident profile

The accident profiles in Appendix B, however, provide an idea of the proportion of wet pavement accidents on various types of roads. Table B8 shows that about 23% of all accidents on MTO roads occur under wet road surface conditions, but it is unclear how much travel is done under these conditions.

A sample of previous research

Perhaps the most relevant recent work was by Sabo and Hauer (**A17.1**) who examined accident experience before and after resurfacing 14 Ontario 2-lane road sections totalling 289.4 km over a 3 year period. After adjusting for accident changes on matched control sections and for traffic volume changes, it was found that the resurfaced sections had a 19.7% reduction in accidents in the first year and a 13.4% reduction in the first 2 years after resurfacing.

Sabo and Hauer cited a number of studies (**A17.2-A17.6**) that accident experience before and after resurfacing, but commented that the reports did not contain sufficient information to cast judgement on their quality. Jorgenson et al. (**A17.2**) summarized the results from five States, with emphasis on data from Ohio, and estimated the safety response after resurfacing at two-lane rural road sites with a wet accident problem, to be of the order of about a 12% accident reduction. Blackburn et al. (**A17.3**) investigated the effectiveness of skid prevention using data from 142 resúrfaced highway sections and an equal number of matched-control sections in 16 States including California, Washington, Maine and Florida. One year before and after data showed an average increase of 2% in the accident rate. The overall wet accident rate decreased by 8%, but the dry accident rate increased by 15%. It was pointed out, however, that the study period included the 1974 energy crisis and the reduction in nationwide speed limit, both of which had pronounced effects on accident experience. Some of the treated sections had other improvements as well which prompted an FHWA study (**A17.4**) that examined the 59 rural two-lane uncontrolled access sections that were resurfaced only. The (total) accident rate was found to increase by 2.2% following resurfacing. The Arkansas State Highway Department

(**A17.5**) analyzed five projects where narrow 2-lane roads totalling 79 km were improved. The one-year accident rate more than doubled for the 4 projects involving only an asphalt overlay while, for the other project, it remained unchanged. Another Alabama study (**A17.6**) examined data before and after resurfacing projects aimed at improving the skid resistance of 24 two-lane rural highway sections totalling 51 km. The accident rate was found to increase by 11.85%.

Many of the studies cited by Sabo and Hauer were reviewed by Cleveland (**A17.7**) in a review of resurfacing conducted for the Transportation Research Board. Based on the review and some extra analysis, Cleveland concluded that typical rural projects at locations selected on the basis of pavement conditions and with low accident rates and a small percent of wet pavement accidents have a small increase in total accident experience, probably of the order of 2% because the increase in dry pavement accidents was larger than the reduction in wet pavement accidents. On the other hand, projects selected because wet pavement accident experience was high, and more than 25% of all accidents, had a meaningful reduction in wet road accidents, probably of the order of 30%, and a reduction in severity, probably of the order of 20% for rural two-lane roads, and more, possibly 40%, elsewhere. [**Comment**: *These findings could be largely due to the regression-to-the mean phenomenon.*]

The wet road accident experience in the data set used by Blackburn et al. (**A17.3**) was further analyzed as a part of Cleveland's review. It was found that resurfacing was particularly effective in reducing the wet accident rate and wet accident frequency on roads with less than 12 ft. lanes but with wider unpaved shoulders. Following resurfacing at these eight sites there was a highly significant 43% reduction in the number of wet accidents. This was accompanied by a 9% increase under other pavement conditions, leading to a significant 9% decrease in total accidents.

A number of studies have addressed the issue of skid resistance and safety. Blackburn et al. (**A17.3**) found that as the skid number, SN increased by 10 the wet accident rate dropped 0.5 accidents/MVM. Karr (**A17.8**) evaluated the effectiveness of grooving in eliminating accidents in order to establish a predictor of accident reduction after grooving. A before and after study was conducted on 39 grooved cement concrete projects in California with 34 miles of total lane length. All except one had two years each of before and after data. Based on 1133 before and 904 after accidents, it was found that, overall, the severe accident rate decreased by 38% and total accidents by 32%, but that the dry weather accident rate increased by 9%. On adjacent (untreated) sections there was little change in the overall accident rate, but the wet weather accident rate increased by 38%.

A supplemental study was conducted by Smith at al. (**A17.9**) to check the validity of Karr's findings (**A17.8**). His two year before and after study of 23 projects covering 322 lane-miles of PCC pavement grooving and 750 miles of ungrooved PCC pavement in California indicated that the wet pavement severe accident rate decreased by 69% while there was no change for dry pavements. It was also concluded that unless the wet pavement accident rate is greater than four times that for dry pavements, grooving would provide little or no improvement.

Other studies on the relationship of skid resistance to safety were of the cross-section type. Ritzenbergs et al. (**A17.10**) examined three years of accident data covering a total of 5907 accidents (1314 occurring during wet weather conditions) on 4-lane rural controlled-access roads in Kentucky. Based on pavement friction measurements at 70 mph it was concluded that the wet surface accident rate increased rapidly as the SN decreased from 27, but that further increases in the SN beyond this point resulted in only a slight reduction in the accident rate.

Ritzenbergs et al. (**A17.11**) also conducted a similar study for 2-lane roads. Based on friction measurements at 50 mph, it was concluded that the ratio of wet to dry accidents decreased rapidly as SN increased to a value of 40, but that further increases in SN beyond this point resulted in only slight reductions in the ratio of wet

to dry pavement accidents.

A 1966 study by McCollough et al. (**A17.12**) examined accident experience for Texas roads with various coefficients of friction and concluded that composite minimum coefficients of 0.4 and 0.3 at testing velocities of 20 and 50 mph respectively should be used as another guide for programming pavement surface improvements. They recommended design values of 0.31 and 0.24.

A final appraisal

Two kinds of studies -- before-and-after and cross-section types --reviewed tend to disagree on the effect of improving skid resistance. Before and after studies showed small or no net benefit of resurfacing (but large benefits from pavement grooving) while large benefits from improving skid resistance are inferred from cross-section studies. It appears that in the cross-section studies, sections with good skid resistance might have been superior in other elements, e.g., geometrics. Nevertheless, there appears to be some consensus that resurfacing reduces the wet pavement accident rate, particularly for pavements with poor skid resistance. It also appears that, under some conditions, the dry accident rate will increase, particularly if geometrics are less than desirable. Thus, whether resurfacing will have net safety benefits depends on the ratio of wet to dry accidents and on the skid resistance.

Assessment of MTO policy

What is desirable for Ontario is not clear from the studies reviewed. The one before-and-after study of Ontario projects appears to be thorough and shows a significant net safety benefit, but the extent to which these projects are representative of resurfacing projects in the province is not clear. Moreover, that study did not address the issue of under what conditions resurfacing for safety might be expected to have a net safety benefit. This type of guidance is necessary as part of an MTO policy on resurfacing for safety resurfacing that should be formalized.

Research needs

It seems desirable for MTO to continue the evaluation of Ontario resurfacing projects by routinely collecting before and after data on accidents, skid resistance, traffic volume and speed for resurfaced as well as surrounding road sections. This information should then be used as a basis for reviewing decision-making on where resurfacing for safety would be beneficial.

References

A17.1 Sabo P. and E. Hauer, "The Safety Effect of Resurfacing Rural Highways". Proceedings, Canadian District Annual Conference, Institute of Transportation Engineers, Hamilton, June 1985.

A17.2 Jorgensen and Associates and Westat Research Analysts, "Evaluation of Criteria for Safety Improvements on the Highway". Report PB-173-822 prepared for the Office of Highway Safety, U.S. Bureau of Public Roads, Galthersburg, Md, October 1966.

A17.3 Blackburn, R.R. et al., "Effectiveness of Alternative Skid Reduction Measures, Vols. I and II". Report nos. FHWA-RD-79-22 and -23, Federal Highway Administration, Washington, D.C., November 1978.

A17.4 Federal Highway Administration, "RRR Alternative Evaluations for Non-Interstate Rural Arterial and Collector Highway Systems". Washington, D.C., March 1980.

A17.5 Arkansas State Highway Department, "Comparison of Accident Rates Before and After Rehabilitation of Narrow Pavements". October 1974.

A17.6 Tignor S. and J.A. Lindley, "Accident Rates on Two-Lane Rural Highways Before and After Resurfacing". Public Roads, Vol. 44 No. 4, March 1981, pp.137-139.

A17.7 Cleveland D., "Effect of Resurfacing on Highway Safety: A Synthesis of Prior Research". TRB 1985.

A17.8 Karr J. "Evaluation of Minor Improvements - Part 8, Grooved Pavements". Traffic Department, State of California, December 1972.

A17.9 Smith R.N. and L.E. Elliot, "Evaluation of Minor Improvements - Part 8, Grooved Pavement Supplemental Report". California Department of Traffic, September 1975.

A17.10 Ritzenbergs R., Burchett J., Napier C., and J.S. Deacon, "Accidents on Rural Interstate and Parkway Roads and Their Relation to Pavement Friction". Transportation Research Record 584, TRB 1976.

A17.11 Ritzenbergs R., Burchett J., and L. Warren, "Relation of accidents and pavement friction on rural two lane roads". Transportation Research Record 633, 1977.

A17.12 McCollough B.F. and K.D. Hankins, "Skid Resistance Guidelines for Surface Improvements on Texas Highways". Highway Research Record 131, HRB 1966.

APPENDIX B: ONTARIO ACCIDENT PROFILES

B.1: INTRODUCTION/DATA

Decisions on focusing roadway safety research should properly be made by considering where accidents occur and where safety benefits could potentially be obtained. Knowledge of Ontario accident experience was gained mainly from analysis of two datasets assembled from data provided by MTO. These are as follows:

(a) A linked dataset of MTO inventory and traffic data and limited data for 1987 accidents.

(b) An accident dataset for 1988 consisting of more detailed information than the 1987 data.

These are described separately below, prior to a presentation and discussion of the Ontario accident profiles. Although more accident data subsequently became available, it was decided not to do any more analysis for this study.

(a) Dataset 1: Linked dataset

Three raw data files were linked to provide a final data set for analysis of accident profiles. The common element that allowed the linking was the coding of information in each file by a number in the Linear Highway Referencing System (LHRS) that indicates which road section the information pertains to. The raw data sets and the preparation and details of the final data set are described below.

The **accident** data set consisted of some details for each of 37,462 accidents reported on MTO roads for the year 1987. Relevant information included severity, vehicle count, and pavement condition (wet, dry, etc.). This data set was already available when the project started, but was lacking in such relevant information as light condition, collision type (nature of vehicle-vehicle and fixed object collisions), driver action, whether the accident occurred at an intersection, and so on.

The **inventory** data set consisted of geometric and other details for each of 3147 LHRS sections and subsections totalling 21563.4 km. Relevant information included road class (freeway etc.), environment (urban/rural), lane and shoulder widths and type, number of lanes, median width and type and so on.

The **traffic** data set contained several elements of traffic data matched to LHRS sections and sub-sections. These include % trucks, AADT and seasonal ADT's.

The **final** linked data set was produced by a series of computer programmes. First, the inventory and traffic data sets were linked. Of the original 3147 sections, traffic data matches were found for about 2833. The remaining 314, representing 10 % of sections and 12.4 % of total km were discarded. Second, for each combined inventory/traffic record, accidents were tallied in 13 categories. Where no accidents were found it was assumed that no accident occurred on that section in 1987. It is recognized that this assumption might lead to slight inaccuracies, especially since there were some 5387 accidents (14.4%) which could not be assigned to an inventory section. It is reasonable to assume, however, that these accidents are more likely to occur on the discarded 12.4% of road kilometers rather than on sections for which no accidents were found.

It was assumed that the discarded inventory sections and accident data would not significantly bias the analysis. Nevertheless, caution must be used in interpreting some of the accident profiles. In particular, to obtain province-wide numbers, e.g., total number of accidents in a particular category, appropriate adjustments should

be applied. Otherwise, all results on accident rates (per million vehicle km) are to be assumed representative of province-wide experience.

(b) Dataset 2: 1988 accident data

This data consisted of selected but detailed information for each of 44,779 accidents recorded for MTO roads in 1988. Since this data became available after the bulk of the work was done for this project, it was not possible to report results here based on a linked traffic and accident dataset for 1988. Yet, as described later, the raw accident dataset used provided several valuable insights on potential target accidents for roadway safety research on specific elements of MTO roads.

B.2: ANALYSIS AND RESULTS

The software package SPSS was used to produce a variety of accident profiles within limits of what was possible with the accident data available. In the remainder of this section a series of Tables is presented and discussed. These profiles are referred to in some of the safety assessments in Appendix A and elsewhere in the body of the report. **For all of the tabulations, caution must be exercised in interpreting the results since cells may be different in features other than those which formed the basis for the tabulations.**

B.2.1: Accident profiles from linked dataset

(a) <u>General characteristics</u>

These are shown in Table B1 and are intended to provide some general ideas on where road safety efforts might be focused.

TABLE B1: GENERAL CHARACTERISTICS OF ACCIDENTS ON MTO ROADS

	URBAN[1]			RURAL		
	Length[2] km	Accidents[2] Number	Accidents[2] Rate[3]	Length[2] km	Accidents[2] Number	Accidents[2] Rate[3]
2-lane primary (Class 2)	131	412 (32)[4]	173 (13)	11928	11335 (1885)	112 (19)
2-lane secondary (Class 3)	46	32 (3)	320 (30)	4425	769 (200)	140 (37)
Multilane Class 2	121	1488 (54)	218 (8)	393	2177 (169)	130 (10)
Multilane freeway (Class 1)	7	97 (8)	386 (29)	1832	15763 (2057)	95 (12)

1 - includes roads in semi-urban environments
2 - based on a sample containing 87.6% of total MTO road kilometers and 85.6% of all accidents on MTO Roads.
3 - Per 100 million vehicle km
4 - Severe accidents (fatal and injury)

(b) Safety experience of roads with different shoulder design

(i) Two-lane rural roads

Table B2 shows single vehicle accident rates for MTO 2-lane rural roads according to shoulder type and width.

Table B2: Single-vehicle accident rates for 2-lane rural roads

Shoulder Type	1987 Accidents (per 100×10^6 veh km) by shoulder width: 0	$\leq$ 1.8m	1.9 - 2.7m	$\geq$ 2.8m
Gravel(Total)		**83.4 (1876)***	**53.6 (2057)**	**39.8 (1087)**
" (Severe)		29.9 (673)	19.7 (757)	13.9 (378)
Part-paved(Tot)		**65.8 (125)**	**40.4 (400)**	**35.2 (278)**
" (Severe)		23.2 (44)	13.5 (134)	13.0 (103)
Paved (Total)		**92.5 (74)**	**57.4 (155)**	**55.0 (22)**
" (Severe)		21.3 (17)	19.3 (52)	15.0 (6)
None(Total)	**38.8 (31)**			
" (Severe)	8.8 (7)			

* - Numbers in parentheses indicate number of accidents from which the rate is computed.

A number of observations can be made. First, roads with wide shoulders have lower accident rates. One must be cautious about inferring that wide shoulders produce lower accident rates since the roads with wide shoulders might generally have superior geometrics, e.g., lane width. Indeed, as Table B3 shows, the average lane width for roads with wide shoulders is larger that for roads with narrow shoulders.

Table B3: Average speed zone and lane width by shoulder classes

Shoulder	0		$\leq$ 1.8m		1.9 - 2.7m		$\geq$ 2.8m	
Type	Speed Zone	Lane Width	Speed Zone	Lane Width	Speed Zone	Lane Width	Speed Zone	Lane Width
Gravel			80.3	3.2	81.9	3.4	82.5	3.6
Part-paved			82.7	3.5	83.5	3.6	82.6	3.6
Paved			80.1	3.3	88.0	3.6	87.9	3.7
None	67.5	4.7						

The second observation from Table B2 is that roads with paved shoulders have the higher single vehicle accident rates than other roads. This might be due to the fact that these roads are zoned for higher speeds, or to vehicles driving on these shoulders. However, it might be that paved shoulders are constructed in locations that are inherently unsafe to begin with. This proposition could not be tested. However, as Table B2 shows, higher speeds on roads with paved shoulders might partly explain the higher accident rates. Finally, the speed factor, as Table B3 shows, might also explain the low accident rates for roads with no shoulder. The Table also indicates that these roads have wider "lanes". In fact, since most of these roads have gravel surfaces where the lane is indistinguishable from the shoulder, they tend to be classified as having "no shoulder".

The final observation from Table B2 is that severe accidents (fatal and injury) also tend to be lower for roads with wider shoulders. The ratio of severe to total single-vehicle accidents appears to be smaller for roads with paved shoulders and for roads with no shoulder. In the latter case, this might be because of slower speeds on both roads. In both cases however, the small numbers of accidents in the cells do not allow for definitive conclusions.

To further examine the influence of speed and lane width, the group of roads with gravel surface and shoulder widths of 1.9 - 2.7m (This group was dominated by roads with 2.4m (8 ft.) shoulders.) was disaggregated by speed zone and lane width. Accident rates for cells having a significant number of accidents are shown in Table B4. As seen, the 80 km/h speed zone dominates. For this group it appears that roads with wider lanes have lower single-vehicle accident rates. Again caution must be used in interpreting this result to mean that wider lanes are safer, since roads with wider lanes might have superior geometrics in general. Also of note in Table B4 is that for a given lane width, roads with a 90 km/h speed zone have a higher single vehicle accident rate than roads with ~~an~~ 80 km/h speed zone.

Table B4: Single-vehicle accident rates by lane width and speed zone for 2-lane rural roads with gravel shoulders 1.9-2.7 km wide

Speed Zone	1987 Accidents (per 100×10^6 veh km) by lane width 2.9-3.18m	3.2-3.37m	3.38-3.58m	3.6-3.66m	3.67-3.8m
80 km/h	68.9 (62)*	52.2 (871)	57.5 (115)	44.0 (400)	49.0 (98)
90 km/h		58.2 (64)	73.3 (22)	72.0 (353)	70.0 (14)

* - Numbers in parentheses indicate number of accidents from which the rate is computed.

(ii) Freeways

Table B5 shows single vehicle accidents for freeways with various shoulder types and widths. A few observations could be made. First, wide shoulders (>2.8m) are dominant. In this width group, freeways with higher type shoulder surface have a lower single vehicle accident rate. According to MTO standards, paved shoulders are more likely to be built on urban freeways, so the observed difference in accident rate by shoulder type could well reflect a difference between urban and rural driving patterns.

Second, for freeways with gravel shoulders the single vehicle accident rate tends to be higher for sections with wider shoulders. As before, this result could not be used to imply causation since sections in different shoulder

width categories could well be different in other features. In addition, this anomalous result might be due to the relatively few accidents on sections with narrow gravel shoulders.

Table B5: Single-vehicle accident rates for freeways

Shoulder Type	1987 Accidents (per $100x10^6$ veh km) by shoulder width: 0	≤ 1.8m	1.9 - 2.7m	≥ 2.8m
Gravel(Total)	30.0 (	9)*	25.7 (18)	44.9 (1774)
Part-paved(Tot)	-	-	45.0 (36)	37.6 (903)
Paved (Total)	38.4 (	96)	28.8 (473)	30.2 (2362)

* - Number of accidents from which the accident rate is computed.

(c) Wet pavement accidents

Table B6 shows the ratio of wet weather accidents to total accidents for various categories of roads. The ratio is quite stable, but appears to be higher for Multi-lane Class 2 roads. It is not clear what to read from this result, except that further analysis could reveal some interesting insights.

TABLE B6: WET PAVEMENT ACCIDENTS FOR VARIOUS ROAD TYPES

	URBAN[1]			RURAL		
	Length km	WET Accidents	Wet/ Total	Length km	WET Accidents	Wet/ Total
2-lane primary (Class 2)	131	103	0.25	11928	2566	0.23
2-lane secondary (Class 3)	46	5	0.16	4426	135	0.18
Multilane Class 2	121	482	0.32	393	696	0.32
Multilane freeway (Class 1)	7	22	0.23	1832	3471	0.22

[1] - Includes semi-urban roads

(d) Accident experience and median design

To examine this issue, one would ideally like to use those accidents involving a vehicle entering the median. Since this is not available at this time, we used single vehicle accidents to gain some preliminary insights and to see whether the pursuit of median design research might be useful. Table B7 shows single vehicle accident rates associated with freeway sections of various median types and widths.

Table B7: Single-vehicle accident rates for freeways by median design

Median Width (m)	1987 Accidents (per 100×10^6 veh km) by Median Type[1] Type 1	Type 2	Type 4	Type 5	Type 6
0.6- 2.0				64.5 (129)	
2.1- 4.7	54.0 (27)[2]	27.7 (909)	21.3 (236)	44.0 (427)	40.0 (100)
4.9- 8.5	46.8 (720)	28.5 (148)	25.2 (53)	26.9 (35)	23.7 (159)
8.8-13.4	40.1 (794)	35.5 (142)	35.2 (148)	43.9 (79)	13.0 (30)
13.7-15.9	35.3 (540)				
16.0-22.6	43.6 (349)				
> 23	39.0 (546)				

[1] - **Type 1:** Grassed depressed; **Type 2:** Raised steel flex beam guide rail; **Type 4:** Raised guide rail with anti glare; **Type 5:** Box beam guide rail; **Type 6:** New Jersey barrier

[2] - Number of accidents from which the accident rate is computed.

Again it is difficult to imply relationships because sections in different cells in Table B7 could be different in features other than median design. Nevertheless, there are sufficient indications to suggest that research on median design and safety might be useful. For example, for depressed grass medians, the single vehicle accident rate tends to be lower for sections with wider medians up to median widths of 13.4m. For Types 2 and 4 raised guide rail, there seems to be a slight trend for sections with wider medians to have a higher single vehicle accident rate. For sections with jersey barriers this trend is reversed and more in accord with intuition.

Finally, for freeways of a given median width, sections with depressed grass medians tend to have the highest single vehicle accident rates, while, for the two median width categories between 4.9 and 13.4m, sections with New Jersey barrier medians have the lowest.

B.2.2: Accident profiles from 1988 accident data

The 1988 accident data, being more detailed, provided valuable information on target accidents that could not be obtained from the 1987 data. Since several references are made to this analysis in the research summaries in Appendix A tabulations based on the 1988 data are provided on the remaining pages without discussion. The full list of tabulations is provided first in a table that also indicates the research summaries relevant to each tabulation. It should be stressed that, because the data was available for only a short time prior to the completion of this project, the analysis could not be as comprehensive as might be desired.

Table B8: 1988 MTO accident tabulations and relevant research summaries

Table #	Description	Applicable summaries
B9	Accidents by severity, location and light condition	A1,A8
B10	Intersection accidents by control type and light conditions	A1,A10
B11	Intersection accidents by control, impact type and severity	A10,A15
B12	Accidents by impact type, severity and location	A3
B13	Accidents on 2-lane roads by impact type, severity, location	A2
B14	Accidents on multilane roads by impact type severity location	A2
B15	2-lane non-intersection accidents by alignment,impact type	A4,A5,A9
B16	Multilane non-intersection accidents by alignment,impact type	A9
B17	Accidents by road character,impact location and severity	A2,A11,A14
B18	Accidents by first object struck or event for first vehicle	A2,A6-7,A12-14

Table B9: 1988 MTO accidents by severity, location and light condition

	n/k	Day	Day Art.	Dawn	Dawn Art.	Dusk	Dusk Art.	Dark	Dark Art.	**TOTAL**
					FATAL-INJURY ACCIDENTS					
TOTAL*	36	233	1	10	0	14	1	159	25	443
Nonint	0	184	0	9	0	13	1	133	22	362
Inter	0	30	1	1	0	0	0	16	3	51
D'way	0	16	0	0	0	1	0	7	0	24
					NON-FATAL INJURY ACCIDENTS					
TOTAL	8	9940	34	354	40	494	55	3909	849	15683
Nonint	3	6254	16	276	35	333	36	2906	704	10563
Inter	3	2650	16	58	2	126	15	710	122	3702
D'way	0	833	0	14	1	28	4	214	10	1104
					PROPERTY DAMAGE ONLY ACCIDENTS					
TOTAL	23	17386	66	739	111	978	125	7583	1612	28623
Nonint	16	11577	43	587	96	706	107	6144	1388	20664
Inter	5	3957	15	101	12	197	16	992	169	5464
D'way	1	1412	3	19	2	56	2	293	10	1798

* All accident locations are included in TOTAL, not just the 3 shown.

CODES:
n/k : not known or other
Art. : Artificial lighting
Nonint: non-intersection
Inter : Intersection (in or related)
D'way : At or near private drive

Table B10: Accidents at intersections by traffic control and light conditions

	n/k	Day	Day Art	Dawn	Dawn Art	Dusk	Dusk Art	Dark	Dark Art	TOTAL
					FATAL ACCIDENTS					
Signal	0	7	0	0	0	0	0	5	3	15
STOP	0	19	0	1	0	0	0	7	0	27
n/k	0	4	1	0	0	0	0	4	0	9
TOTAL	0	30	1	1	0	0	0	16	3	51
					NON-FATAL INJURY ACCIDENTS					
Signal	1	1100	7	26	2	44	8	286	84	1558
STOP	1	806	6	14	0	46	1	201	6	1081
n/k	1	744	3	18	0	36	7	223	32	1106
TOTAL	3	2650	16	58	2	127	15	710	122	3702
					PROPERTY DAMAGE ONLY ACCIDENTS					
Signal	0	1591	6	44	7	79	9	382	103	2221
STOP	3	1151	5	24	0	47	3	263	21	1517
n/k	2	1215	4	33	5	71	4	347	47	1729
TOTAL	5	2742	15	101	12	197	16	992	124	3735
					ALL INTERSECTION ACCIDENTS					
Signal	1	2698	13	70	9	123	17	673	190	3794
STOP	4	1976	11	39	0	93	4	471	27	2625
n/k	3	1963	8	51	5	107	11	574	79	2844
TOTAL	8	6637	32	160	14	323	32	1718	296	9263

NOTE: n/k for control type includes almost all listed as no control. Most likely these might be where vehicle 1 is on the major road of a stopped control intersection.

CODES: n/k - not known or other (See Note above)
Art - Artificial

Table B11: Intersection accidents by control, impact type and severity

	Appr	Ang	r/e	si/sw	turn	sv/u	sv/o	Other	TOTAL
				TRAFFIC SIGNAL CONTROLLED					
Fatal	0	7	0	0	6	0	2	0	15
Injury	11	212	577	29	584	2	141	2	1558
PDO	12	229	647	153	881	5	268	26	2221
				STOP-CONTROLLED					
Fatal	3	14	0	0	7	0	12	0	36
Injury	51	392	545	67	594	4	488	3	2144
PDO	36	418	650	245	1040	16	803	35	3243
TOTAL	113	1272	2419	494	3112	27	1714	66	9217

Codes for impact type: See Table B12.

Table B12: 1988 MTO accidents by impact type, severity and location

	Appr	Ang	r/e	si/sw	turn	sv/u	sv/o	Other	TOTAL
FATAL ACCIDENTS									
Total	115	28	23	21	20	2	256	8	473
Nonint	98	1	20	11	2	2	227	1	362
Inter	3	21	0	0	13	0	14	0	51
D/way	3	3	1	1	5	0	9	2	24
NON-FATAL INJURY ACCIDENTS									
Total	644	685	4546	1087	1655	121	6924	22	15684
Nonint	553	20	2994	933	45	104	5898	17	10564
Inter	62	604	1122	96	1178	6	629	5	3702
D/way	22	58	323	31	431	7	232	0	1104
PROPERTY DAMAGE ONLY ACCIDENTS									
Total	410	854	6211	3642	2732	266	14368	139	28622
Nonint	330	13	4405	3051	44	217	12543	60	20663
Inter	48	647	1297	398	1921	21	1071	61	5464
D/way	20	191	359	101	766	20	324	17	1798
TOTAL	1169	1567	10780	4750	4407	389	21548	169	44779

Codes:

Nonint: Non intersection;
Inter: Intersection;
D'way: Driveway
Appr : Approaching
Ang : Angle
r/e : Rear end
si/sw: side swipe
turn : Turning movement
sv/u : single vehicle (unattended)
sv/o : single vehicle (other)

Table B13: Accidents on 2-lane roads by impact type, severity, location

	Appr	Ang	r/e	si/sw	turn	sv/u	sv/o	Other	TOTAL
					FATAL ACCIDENTS				
Total	87	16	6	4	10	0	130	2	255
Nonint	82	1	6	4	2	0	112	0	207
Inter	2	12	0	0	4	0	9	0	27
D'way	3	2	0	0	4	0	7	2	18
					NON-FATAL INJURY ACCIDENTS				
Total	508	402	1232	310	826	42	3631	9	6960
Nonint	444	15	532	245	32	34	3026	6	4334
Inter	40	359	469	39	545	2	362	3	1819
D'way	20	26	206	21	249	6	182	0	710
					PROPERTY DAMAGE ONLY ACCIDENTS				
Total	322	479	1518	816	1431	140	7620	64	12390
Nonint	266	6	720	618	19	108	6569	18	8324
Inter	32	380	517	118	960	9	597	31	2644
D'way	16	91	248	53	452	19	270	14	1163
TOTAL	917	897	2756	1130	2267	182	11381	75	19605

Codes: See Table B12.

Table B14:Accidents on multilane roads by impact type severity location

	Appr	Ang	r/e	si/sw	turn	sv/u	sv/o	Other	TOTAL
					FATAL ACCIDENTS				
Total	17	10	15	8	10	2	120	1	183
Nonint	16	0	14	7	0	2	110	1	150
Inter	1	9	0	0	9	0	5	0	24
D'way	0	1	1	1	1	0	2	0	6
					NON-FATAL INJURY ACCIDENTS				
Total	127	268	3203	762	807	78	3034	13	8292
Nonint	102	5	2406	681	13	69	2668	11	5955
Inter	21	230	598	52	612	4	224	2	1743
D'way	2	32	117	9	181	1	45	0	387
					PROPERTY DAMAGE ONLY ACCIDENTS				
Total	80	357	4516	2763	1249	114	6208	70	15357
Nonint	58	5	3593	2390	25	99	5535	41	11746
Inter	16	253	706	265	913	10	392	26	2581
D'way	4	98	108	46	310	1	50	3	620
TOTAL	224	635	7734	3533	2066	194	9362	84	23832

Codes: See Table B12.

Table B15: 2-lane non-intersection accidents by alignment,impact type

	Appr	Ang	r/e	si/sw	turn	sv/u	sv/o	other	TOTAL
FATAL ACCIDENTS									
Total	82	1	6	4	2	0	112	0	207
St/Level	52	1	5	1	2	0	56	0	117
St/Hill	8	0	0	0	0	0	17	0	25
Cur/Lev	12	0	1	1	0	0	29	0	43
Cur/Hill	0	0	0	1	0	0	0	0	1
NON-FATAL INJURY ACCIDENTS									
Total	444	15	532	245	32	34	3025	6	4333
St/Level	351	12	436	194	28	14	2041	4	3080
St/Hill	24	1	19	14	2	4	348	0	412
Cur/Lev	15	0	15	8	0	0	121	0	159
Cur/Hill	13	0	5	4	0	2	55	0	79
PROPERTY DAMAGE ONLY ACCIDENTS									
Total	266	6	720	618	19	108	6569	18	8324
St/Level	211	5	623	499	16	52	5380	15	6801
St/Hill	7	0	11	12	3	3	289	0	325
Cur/Lev	6	0	9	9	0	3	93	0	120
Cur/Hill	1	0	1	4	0	2	34	1	43
ALL ACCIDENTS									
Total	792	22	1258	867	53	142	9706	24	12864
St/Level	614	18	1064	694	46	66	7477	19	9998
St/Hill	39	1	30	26	5	7	654	0	762
Cur/Level	33	0	25	18	0	3	243	0	322
Cur/Hill	14	0	6	9	0	4	89	1	123

Codes: St/Level: Straight on Level; St/Hill: Straight on Hill
Cur/level: Curve on Level; Cur/Hill: Curve on Hill

Table B16: Multilane non-intersection accidents by alignment,impact type

	Appr	Ang	r/e	si/sw	turn	sv/u	sv/o	other	TOTAL
				FATAL ACCIDENTS					
Total	16	0	14	7	0	2	110	1	150
St/Level	10	0	10	6	0	0	63	1	90
St/Hill	3	0	0	0	0	0	10	0	13
Cur/Level	1	0	1	0	0	1	17	0	20
Cur/Hill	0	0	1	0	0	1	1	0	3
				NON-FATAL INJURY ACCIDENTS					
Total	102	5	2406	681	13	69	2668	11	5955
St/Level	78	5	1901	540	12	26	1896	7	4465
St/Hill	6	0	68	20	0	5	199	1	299
Cur/Level	5	0	44	9	0	4	86	1	149
Cur/Hill	6	0	15	12	1	2	32	0	68
				PROPERTY DAMAGE ONLY ACCIDENTS					
Total	58	5	3593	2390	25	99	5535	41	11746
St/Level	46	5	3028	1863	24	54	4335	36	9391
St/Hill	2	0	44	43	0	6	187	1	283
Cur/Level	3	0	29	31	0	1	83	0	147
Cur/Hill	0	0	4	11	0	1	27	0	43
				ALL ACCIDENTS					
Total	176	10	6013	3078	38	170	8313	53	17851
St/Level	134	10	4939	2409	36	80	6294	44	13946
St/Hill	11	0	112	63	0	11	396	2	595
Cur/Level	9	0	74	40	0	6	186	1	316
Cur/Hill	6	0	20	23	1	4	60	0	114

Codes: St/Level: Straight on Level; St/Hill: Straight on Hill
Cur/level: Curve on Level; Cur/Hill: Curve on Hill

Table B17: 1988 accidents by road character,impact location and severity

	Oth	un-1	un-2	di/ba	div	ramp	coll	expr	trans	TOTAL
1F	0	0	36	0	2	0	0	0	0	38
1I	2	14	1657	46	108	160	4	7	0	1998
1P	1	34	2203	88	137	295	9	10	1	2778
2F	0	1	163	25	48	3	5	2	0	247
2I	2	51	3601	1837	812	387	527	586	24	7827
2P	6	102	6514	3884	1662	900	1061	1129	80	15338
3F	0	0	0	0	0	0	0	0	0	0
3I	0	1	132	9	18	22	0	1	0	183
3P	1	5	257	19	33	58	1	1	0	375
4F	0	0	0	0	0	0	0	0	0	0
4I	0	2	58	5	9	40	0	0	0	114
4P	0	12	150	18	19	66	1	1	0	267
5F	0	0	0	0	0	0	0	0	0	0
5I	0	5	14	4	2	15	0	0	0	40
5P	0	15	17	7	6	28	1	1	0	75
6F	0	0	0	0	0	0	0	0	0	0
6I	0	0	23	0	0	2	0	0	0	25
6P	0	1	68	1	0	3	0	0	0	73
7F	0	0	1	0	2	0	0	0	0	3
7I	1	4	115	30	75	1	2	6	0	234
7P	1	3	167	105	174	9	5	8	0	472
8F	0	0	6	1	5	0	2	1	0	15
8I	0	4	267	219	88	72	40	45	3	738
8P	0	8	689	720	121	142	77	98	11	1866
9F	0	0	13	4	1	1	1	1	0	21
9I	0	4	466	119	152	51	20	30	6	848
9P	0	20	1148	289	276	154	44	55	10	1996
10F	0	1	37	2	14	0	0	3	1	58
10I	0	9	929	136	377	122	35	34	5	1647
10P	0	17	1232	378	326	194	86	84	9	2326
11F	0	1	29	5	11	3	0	1	1	51
11I	0	10	1053	184	352	81	23	20	2	1725
11P	0	23	1548	255	424	175	66	43	12	2546
12F	0	0	6	0	2	0	0	0	0	8
12I	0	6	164	14	33	3	0	1	0	221
12P	2	3	227	14	36	15	0	2	0	299
13F	0	0	3	0	0	0	0	0	0	3
13I	0	2	52	8	9	16	3	0	2	92
13P	0	6	138	19	35	31	4	4	1	238
TOTAL	16	364	23183	8445	5369	3049	2017	2174	168	44785

Severity codes: F: Fatal; **I:** Injury; **P:** Property Damage.
Road character codes: un-1(2): undivided 1(2) way; **di/ba**; Divided with barrier; **div:** Divided; **coll:** collector; **expr:** express; **trans:** transfer;
Impact location codes: 1: within intersection; 2: thru lane; 3: left-turn lane; 4: right turn lane; 5: right turn channel; 6: 2-way left turn lane; 7: passing lane; 8: left shoulder; 9: right shoulder; 10: off-road right side; 11: off-road left side; 12: off-highway; 13: other.

TABLE B18: 1988 accidents on MTO roads by severity and first object struck or event for first vehicle

Description	MTO Code	FATALS	INJURY	PDO
MOVEABLE OBJECTS				
Other motor vehicle	1	189	8668	14131
Unattended vehicle	2	2	77	196
Pedestrian	3	40	141	2
Cyclist	4	6	95	3
Train	5	1	3	3
Farm tractor	7	0	10	15
Animal - domestic	8	0	37	130
Animal - wild	9	0	169	1987
Other moveable object	97	0	5	12
NON-COLLISION EVENTS				
Ran off road	20	100	2409	2693
Skidding or sliding	21	67	1950	4178
Jack knifing	22	1	37	143
Load spill	23	1	9	56
Fire or explosion	24	0	6	352
Submersion	25	0	1	0
Rollover	26	3	321	267
Debris on road	27	1	48	203
Debris fall off vehicle	28	0	29	141
Other non-collision	98	6	454	1005
FIXED OBJECTS				
Cable guide rail	50	1	111	527
Concrete guiderail	51	1	91	225
Steel guiderail	52	7	289	984
Pole (utility tower)	53	2	67	132
Pole (sign, park meter)	54	2	66	238
Fence or noise barrier	55	0	15	52
Culvert	56	1	18	14
Bridge support	57	0	13	45
Rock face	58	1	48	49
Snow bank or drift	59	0	51	129
Ditch	60	8	258	308
Curb	61	3	100	181
Crash cushion	62	0	6	16
Building or wall	63	0	9	12
Water course	64	0	2	1
Construction marker	65	0	8	33
Tree, shrub or stump	66	0	25	28
Other	99	1	45	159

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